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THE FORCE AND MOMENT ON A SUBMERGED AXISYMMETRIC BODY MOVING NEAR A SINUSOIDAL WALL

JOSEPH TIMOTHY ARCANO, JR.

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O.E. JUNE 1985

THE FORCE AND MOMENT ON A SUBMERGED AXISYMMETRIC BODY MOVING NEAR A SINUSOIDAL WALL

By

Joseph Timothy Arcano, Jr.

B.S.O.E., United States Naval Academy
(1978)

SUBMITTED TO THE DEPARTMENT OF OCEAN ENGINEERING
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JUNE, 1985

The Force and Moment on a Submerged Axisymmetric Body

Moving Near a Sinusoidal Wall

By

Joseph Timothy Arcano, Jr.

Submitted to the Department of Ocean Engineering on May 10, 1985 in partial fulfillment of the requirements for the degrees of Ocean Engineer and Master of Science in Mechanical Engineering.

ABSTRACT

The hydrodynamic force and yaw moment acting on a slender axisymmetric body are found for the case in which the body is moving along its axis with constant forward velocity parallel to a vertical wall. The fluid is assumed to be inviscid and incompressible.

First, the situation of a body near a flat wall is addressed using the method of images. The body and its image are modeled using a continuous line distribution of sources and doublets; the dipole distribution is used to account for velocities induced on each body by its image.

Next, the case of a body running parallel to the mean position of a wall varying sinusoidally in the longitudinal direction is analyzed. The interaction between the sinusoidal wall and body is modeled using a "large" axisymmetric body in proximity of a smaller body. The quasi-static case is investigated, that is, the body and wall are held fixed in a uniform stream.

The transverse force and moment on a body near each type of wall are determined using two different methods: Lagally's theorem and "segmented" theory. ("Segmented" refers to dividing the body into vertical segments and calculating the force on each segment using either a two or three-dimensional flow analysis, whichever is appropriate. In the two-dimensional case, the segments correspond to "strips" used in strip theory.) Lagally`s theorem is used to find the axial force on a body near a sinusoidal wall.

Computer programs and calculated results are presented for an unappended modern submarine hull form in the vicinity of both types of walls. Force and moment are found to increase rapidly as the distance between wall and body decreases. In the flat wall case, Lagally and segmented theory calculations correlate well with model test results. For the sinusoidal wall problem, results are plotted indicating how force and moment vary with wall amplitude and longitudinal location of the body with respect to the wall sinusoid.

Thesis Supervisor: Martin A. Abkowitz
Title: Professor of Ocean Engineering

ACKNOWLEDGMENTS

The author respectfully dedicates his efforts to those men and women who helped forge this great nation into what it is - to those who unselfishly lived and died by the motto "Non sibi, sed patriae." For without their efforts, experiences such as an MIT education would not be possible.

Also, I would like to thank Professor Martin Abkowitz for his invaluable guidance and experience concerning the practical aspects of hydrodynamics through his introduction of realistic concepts to hydrodynamic theory.

Last, but not least, I wish to thank my wife, Brenda, and son, Joey, for their never ending patience and love throughout the course of my endeavors at MIT.

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NOMENCLATURE

A	cross-sectional area of body
A_{22}	lateral added mass of a segment
A_{wall}	amplitude of wall sinusoid
d	diameter of submarine hull form
D	diameter of approximated "wall" body
d_L	axial distance between the origin of the submarine hull form (amidships) and the nodal point of the wall sinusoid
F	force
L	length of the submarine hull form
$m(\xi)$	local source strength
M	moment
$\hat{n}$	unit normal vector
q	induced velocity
$r(\xi)$, $r(x)$	local radius of a body
r_o, r	radius of a body
r_{12}	distance between points 1 and 2
$\vec{r}$	position vector
R	radius of two-dimensional cylinder
S	separation distance between outermost portion of the submarine hull and the mean position of the wall
u	induced longitudinal velocity
v	induced transverse velocity
w	induced vertical velocity

NOMENCLATURE CONT.

U	forward velocity of submarine hull form
V	uniform transverse velocity
V_n	normal velocity
ϕ	velocity potential
λ_{wall}	wavelength of wall sinusoid
ξ	"dummy" variable indicating axial position
ρ	water density
$\zeta(\xi)$	local doublet strength

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CHAPTER ONE

INTRODUCTION

A submarine running parallel to a wall in an otherwise unbounded fluid experiences forces and moments which are a function of the velocity of the submarine as well as its proximity to the wall. These forces and moments arise due to the reduced pressure between the hull and wall caused by flow velocities in this region being greater than anywhere else around the body surface; this phenomenon is commonly referred to as the Venturi effect.

The force developed always tends to pull the submarine towards the wall. However, the direction of the moment is a function of body shape. Within potential theory, no net moment would act on a body with fore and aft symmetry near a flat wall. For a modern submarine with blunt bow and tapering afterbody, the flow over the bow is accelerated much more than that over the stern, resulting in a moment which tends to rotate the bow toward the flat wall.

This problem is of practical interest for a submarine operating in the vicinity of the ocean bottom. These forces and moments are destabilizing to the vessel's motion and will pull the submarine off its intended course into the bottom unless accounted for. However, if the force and moment acting on a body in this situation can be predicted, then a control system can be devised which compensates for these destabilizing

effects. By using a high resolution sonar to sense the boundary surface contour, such a control system might permit high speed operation in the vicinity of the ocean bottom.

PROBLEM FORMULATION

In order to determine the force and moment acting on a submarine, the problem must first be idealized: the case of an unappended slender (radius/length << 1) axisymmetric body in the vicinity of a wall with no other bodies in proximity shall be considered. The fluid is assumed to be ideal (inviscid) and incompressible.

The particular body shape analyzed will be one representative of modern submarine hull forms, described by the following characteristics:

Length Overall / Diameter	11
Forebody Length / Length Overall	.17
Forebody Fullness Factor	2
Afterbody Length / Length Overall	.44
After Fullness Factor	3

Refer to Appendix A, "Hull Geometry Description of a Modern Submarine" for further detail.

PREVIOUS AND RELATED WORK

Eisenberg[1] considered the problem of a spheroid moving in the proximity of a wall using a source distribution to represent the body, and a corresponding image source system

beyond the wall. Using this analysis, an approximate velocity potential was obtained from which the pressure distribution on the body could be calculated. The force and moment could then be determined by integrating the pressure distribution over the body surface. However, Eisenberg failed to account for velocities induced on each body by its image and therefore, this approximation is good only in the situation where the body and its image are far apart.

Newman[2] applied slender body theory to a set of images and accounted for the induced velocities by offsetting the source distribution an appropriate distance from the body axis. This approach, however, is only good for bodies in the immediate proximity of the wall; the force and moment fail to decrease as rapidly as they should as the distance between the wall and body increases.

PRACTICAL CONSIDERATIONS

The above-mentioned approaches are concerned with bodies in the vicinity of a flat wall. However, the ocean floor is generally not flat, but rather, an irregular surface which can be described only in a statistical manner. The irregular wall problem, therefore, warrants investigation.

First, the case of an axisymmetric slender body moving with constant velocity parallel to a flat wall will be approached using an axial distribution of singularities to model the body and a corresponding image system to account for

the wall.

Next, the irregular wall problem will be addressed. As a first step towards analyzing the case of an irregular wall, a sinusoidal wall, varying in longitudinal direction only, will be investigated to simplify the problem. The problem will be limited further to consider the "quasi-static" case in which the body and wall are fixed in a uniform flow field of constant velocity parallel to the body axis at infinity.

The force and moment will be analyzed over separation distances ranging from one-half to five body diameters between the hull and wall. At distances greater than five diameters, it is anticipated that the force and moment acting on the body will be negligible. Distances less than one-half diameter are not considered to be of practical importance due to navigational considerations.

FLAT WALL ANALYSIS

The force and moment acting on an axisymmetric body moving parallel to a flat wall can be determined using either Lagally's theorem (Appendix C) or segmented theory (Appendix D) after a velocity potential function ϕ has been constructed which meets the appropriate boundary conditions. The applicable boundary conditions are:

1. Zero flow normal to the body surface,

that is, $$V_n = \frac{\partial\phi}{\partial n}\bigg|_{S_{body}} = 0$$

and

2. Zero flow normal to the wall,

that is, $$V_n = \frac{\partial\phi}{\partial n}\bigg|_{S_{wall}} = 0$$

where $\frac{\partial}{\partial n}$ is the derivative in the direction of the unit normal $\hat{n}$ out of the fluid. The governing equation throughout the fluid domain is Laplace's Equation, $\nabla^2\phi=0$, which is an expression of the conservation of mass for a potential function.

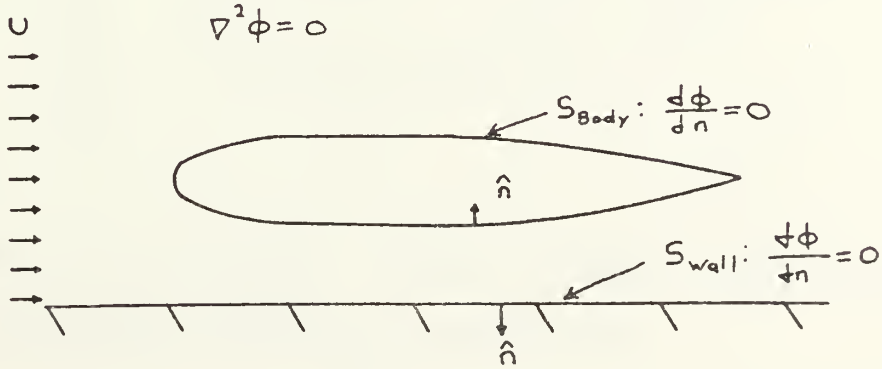

FIGURE 1: Boundary Conditions for a Body Near a Flat Wall

The axisymmetric slender body alone in an infinite fluid can be modeled using a line distribution of sources as explained in Appendix B, "Modeling an Axisymmetric Body."

The interaction between the body and wall is taken into account by meeting the boundary condition of zero flow normal to the wall, that is, $\left.\frac{\partial\phi}{\partial n}\right|_{S_{wall}} = 0$. This is done using the method of images in which the wall is "replaced" by an image (which corresponds to the body) located symmetrically beyond the wall. Any motion of the body is "mirrored" by its image and therefore, each body contributes a flow normal to the wall equal in strength yet opposite in direction. The resulting net flow across the wall is thus zero.

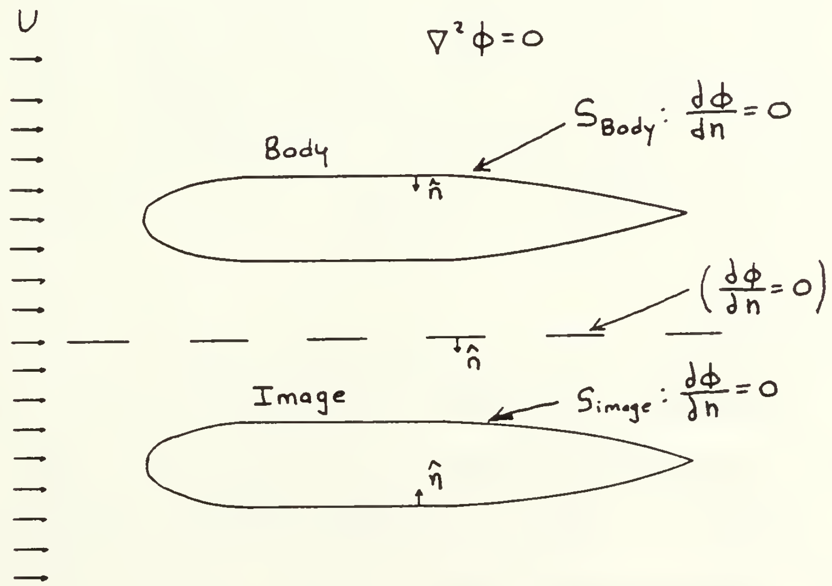

FIGURE 2: Body and its Image. (Note That $\frac{\partial\phi}{\partial n} = 0$ Along the Line of Symmetry Between the Two Bodies)

A body in the proximity of a flat wall can therefore be modeled by establishing the velocity potential for two geometrically similar bodies of equal size moving parallel to one another at constant forward velocity in an otherwise infinite fluid. Appendix B presents the techniques necessary to establish this velocity potential.

CALCULATING THE FORCE AND MOMENT

Computer programs (presented in Appendix F) to calculate the force and moment on a modern submarine hull near a wall were created based on the following considerations:

The body and its image can both be sized independently using continuous source distributions in a uniform flow. When these two distributions are brought into proximity, each will induce velocities over the other body's surface which will disturb the body boundary conditions previously satisfied. However, by using a slender body approximation, a continuous dipole distribution can be sized to restore the surface boundary conditions.

It can be seen, though, that these boundary conditions are not yet fully satisfied since the velocities induced on each body are now caused not only by the source distribution, but by the newly introduced doublet system as well. However, the singularity distributions used to model both bodies can be resized until ultimately, a system of sources and dipoles which satisfies all boundary conditions is converged upon (Reference 3).

Figures 3 and 4 show the source and dipole strengths during the iteration process of sizing a singularity system to represent a modern submarine hull form. (The body's velocity is one foot per second and is located with a separation distance of one-tenth of a body diameter between hull and wall.) With iteration, the source strength remains essentially constant, reflecting negligible (as compared with the forward velocity) induced longitudinal flow along the body and image. However, dipole strength is shown to increase significantly between the first and fifth iterations.

As the body is moved closer to its image, the number of iterations until convergence increases since the velocities induced on each body are greater. For this reason, an iteration analysis was performed. It was found that for separation distances down to one-half of a diameter, convergence is guaranteed within three iterations; for distances down to one-tenth of a diameter, five iterations are required; for distances less than one-tenth of a diameter, the number of iterations until convergence increases rapidly. In the "immediate" vicinity of the wall, however, the iteration procedure is divergent and therefore, the velocity potential in this situation cannot be predicted using this method.

Once the velocity potentials for the body and its image have been converged upon, the force and moment on the body can be determined using either Lagally's theorem (Appendix C) or segmented theory (Appendix D).

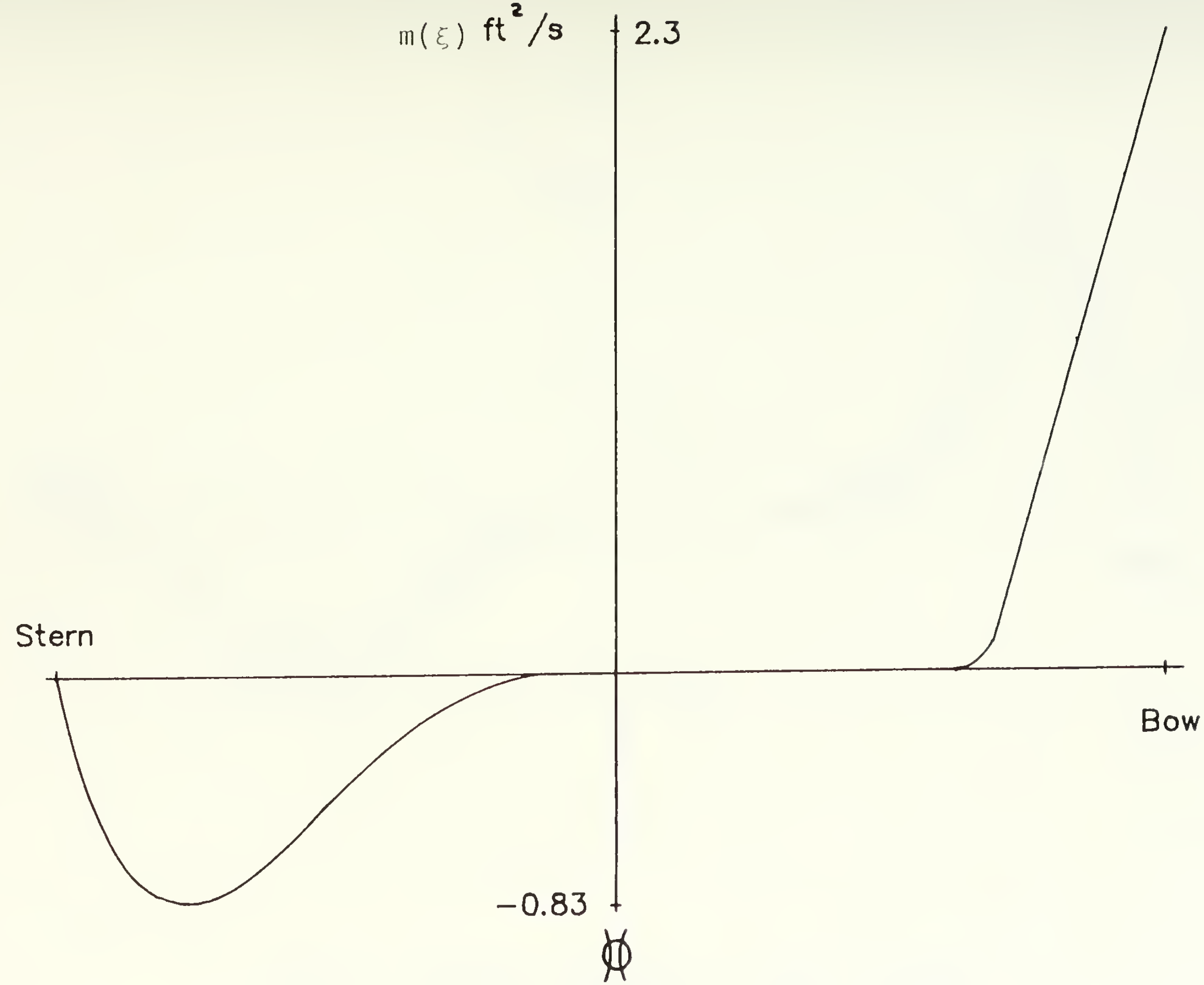

Figure 3. Source Strength vs. Axial Location

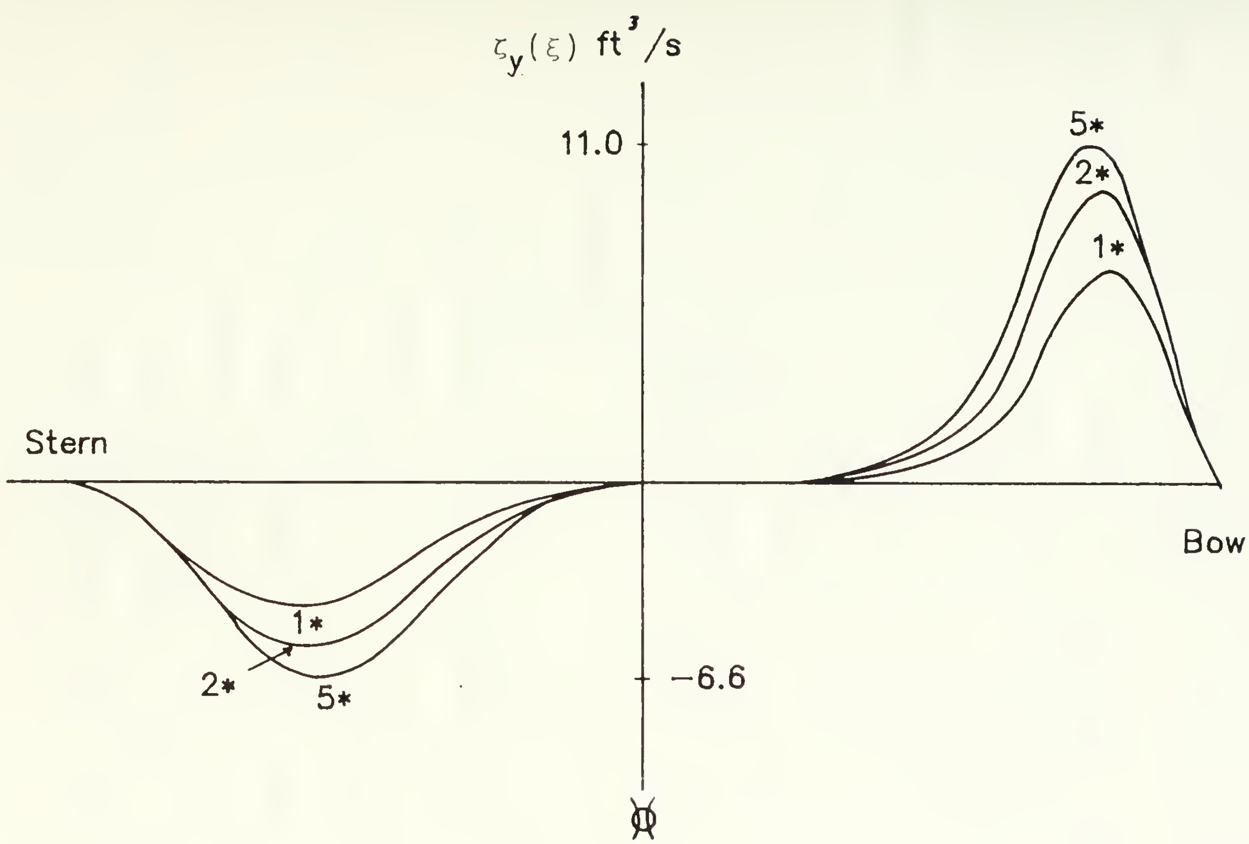

Figure 4. Dipole Strength vs. Axial Location
(* indicates iteration number)

The segmented theory presented in this thesis can be used to calculate only the transverse force on a body; a method of determining the axial force is still to be developed. However, since no axial force is anticipated for the flat wall case, this poses no problem at this time.

Segmented theory offers a distinct advantage over Lagally's theorem in that the appendages on a body can be accounted for in the calculations. By merely including the appendages when calculating the added mass of a segment, the force and moment on an appended hull can be determined. For the purposes of this thesis, however, the appendages will not be included in the segmented theory calculations in order to remain consistent with the other methods against which this technique is compared.

Lagally's theorem predicts the moment acting on a body based on the location of the singularities which describe its shape, which for a modern submarine hull form are concentrated at the bow and stern. In actuality, the forces which generate the yawing moment act over the entire body length. Because the segmented theory approach determines the transverse force at each segment along the body length, this theory's moment results should be more accurate that those found using Lagally's theorem.

CALCULATED RESULTS

As a function of separation distance S (Figure 5), the transverse force and yaw moment on a representative modern submarine hull form, calculated using both the Lagally and segmented theories, are plotted and compared with Newman's slender body theory in Figures 6 and 7. For segmented theory, a two-dimensional analysis is used along the length of the body except for the region extending from the bow aft a distance of one-twentieth of the overall length. A three-dimensional analysis is used on this segment.

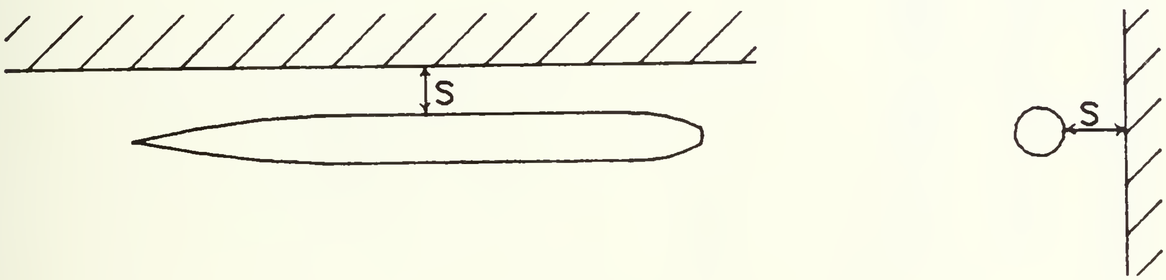

FIGURE 5: Separation Distance S

Axial force was calculated using Lagally's theorem to be essentially zero as anticipated near a flat wall.

S ranges from one-half to five body diameters.

Force is normalized by $1/2\ \rho U^2 L^2 \times 10^{-4}$; moment is normalized by $1/2\ \rho U^2 L^3 \times 10^{-5}$. (U is body forward velocity; L is body length.) Primes are used to indicate normalized quantities, for example , $F' = F/(1/2\ \rho U^2 L^2 \times 10^{-4})$.

As expected, both transverse force and moment increase rapidly as the body is moved closer to the wall. Segmented

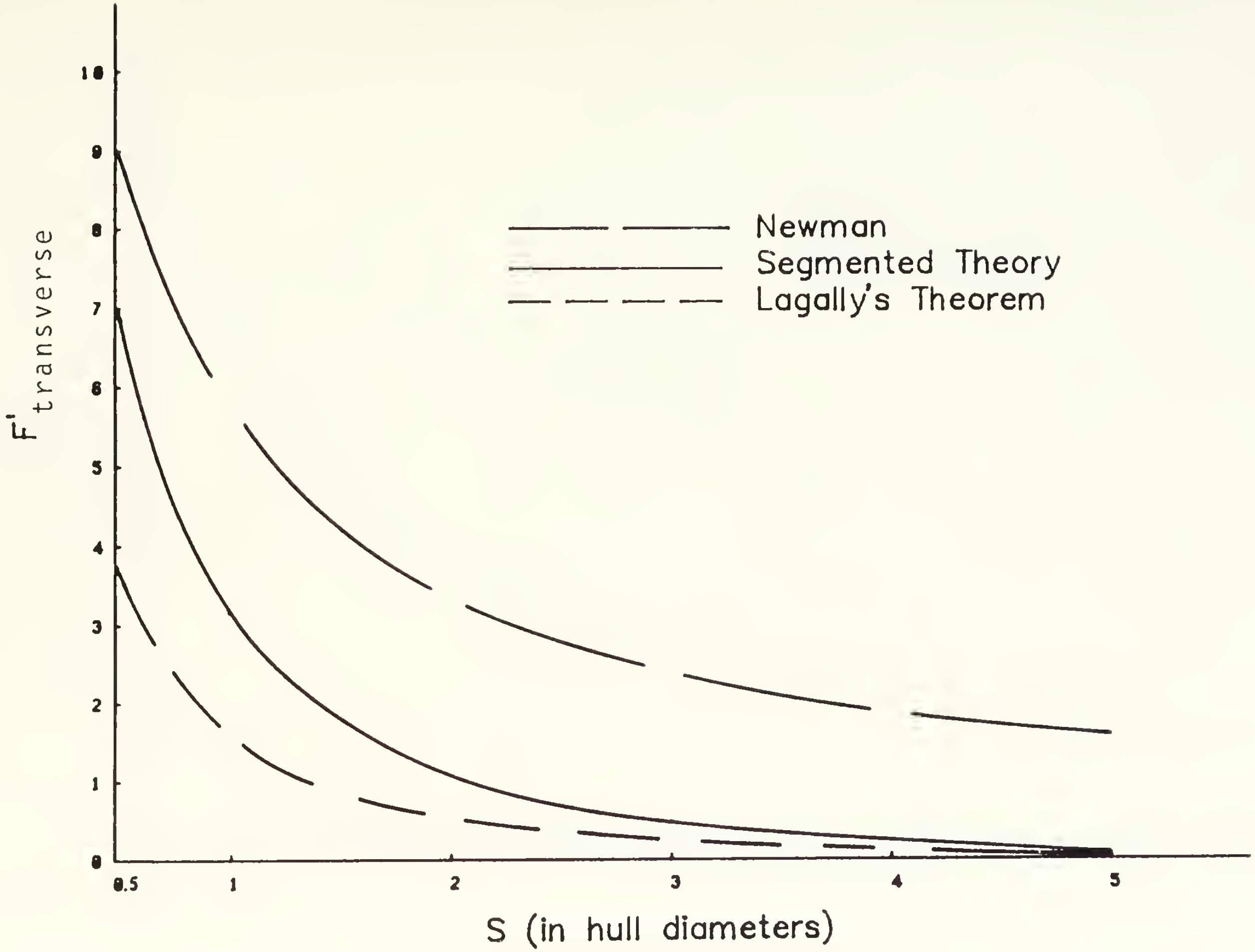

Figure 6. The Transverse Force Acting on a Modern Submarine Hull Form in the Vicinity of a Flat Wall.

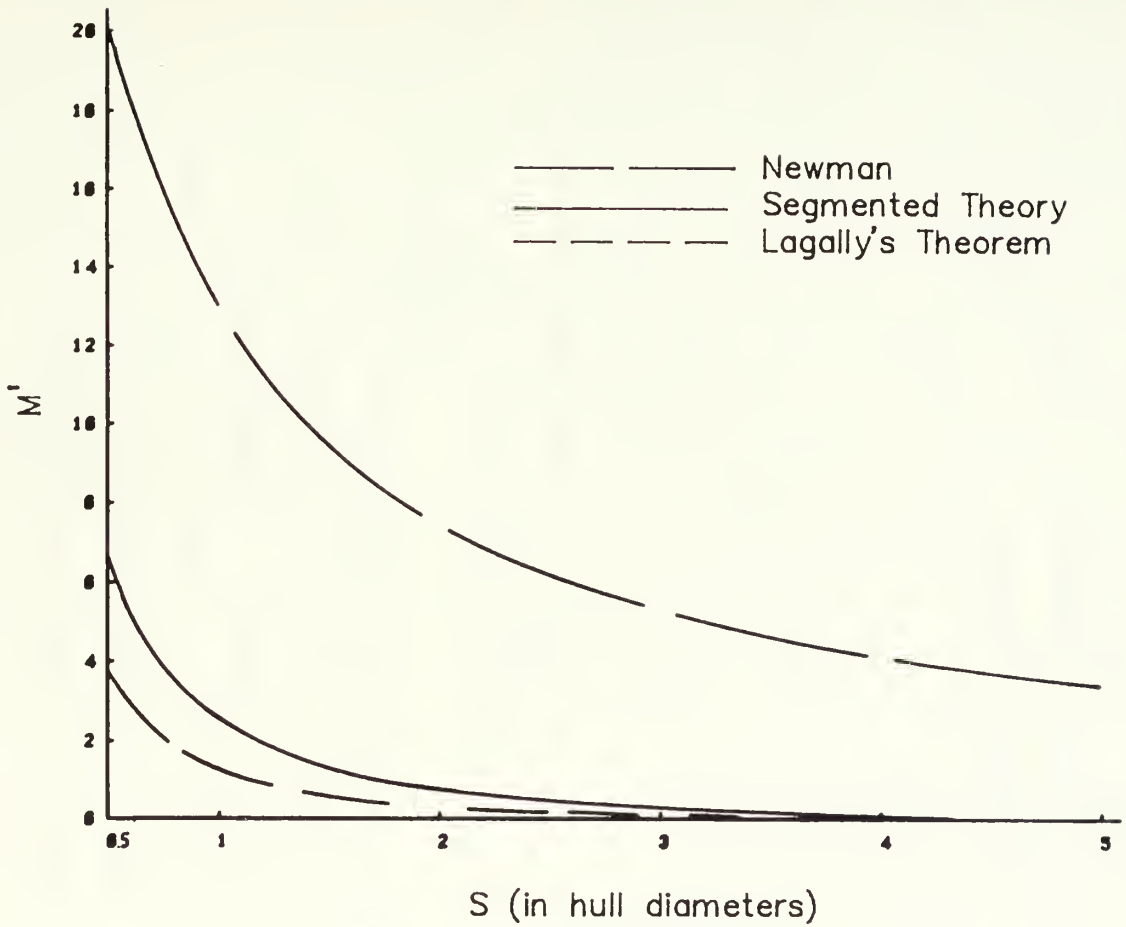

Figure 7. The Moment Acting on a Modern Submarine Hull Form in the Vicinity of a Flat Wall.

theory force calculations approach Newman's theory near the wall, however, they move closer to the Lagally results as the separation distance is increased.

All three techniques predict "bow-in" yaw moments which is physically correct for a blunt-nosed modern submarine with tapering afterbody. Lagally and segmented theory calculated moments are comparable, both becoming negligible at a separation distance of approximately three to four hull diameters. However, results from both of these methods differed significantly from those using Newman's theory.

For the purpose of comparison, the normalized drag (composed primarily of frictional drag with some form drag) on this unappended modern submarine hull form in a real but infinite fluid is approximately $F'_{drag} = 4.7$. It is interesting to note that the predicted transverse force is of the same order of magnitude.

In Figure 8, force calculations are compared with the results of model tests performed on an actual modern submarine hull form in the vicinity of a wall. Although the tests were done using an appended hull, the force in this case should not differ too much from the unappended condition. Lagally and segmented theory force calculations are shown to correlate well with the test results.

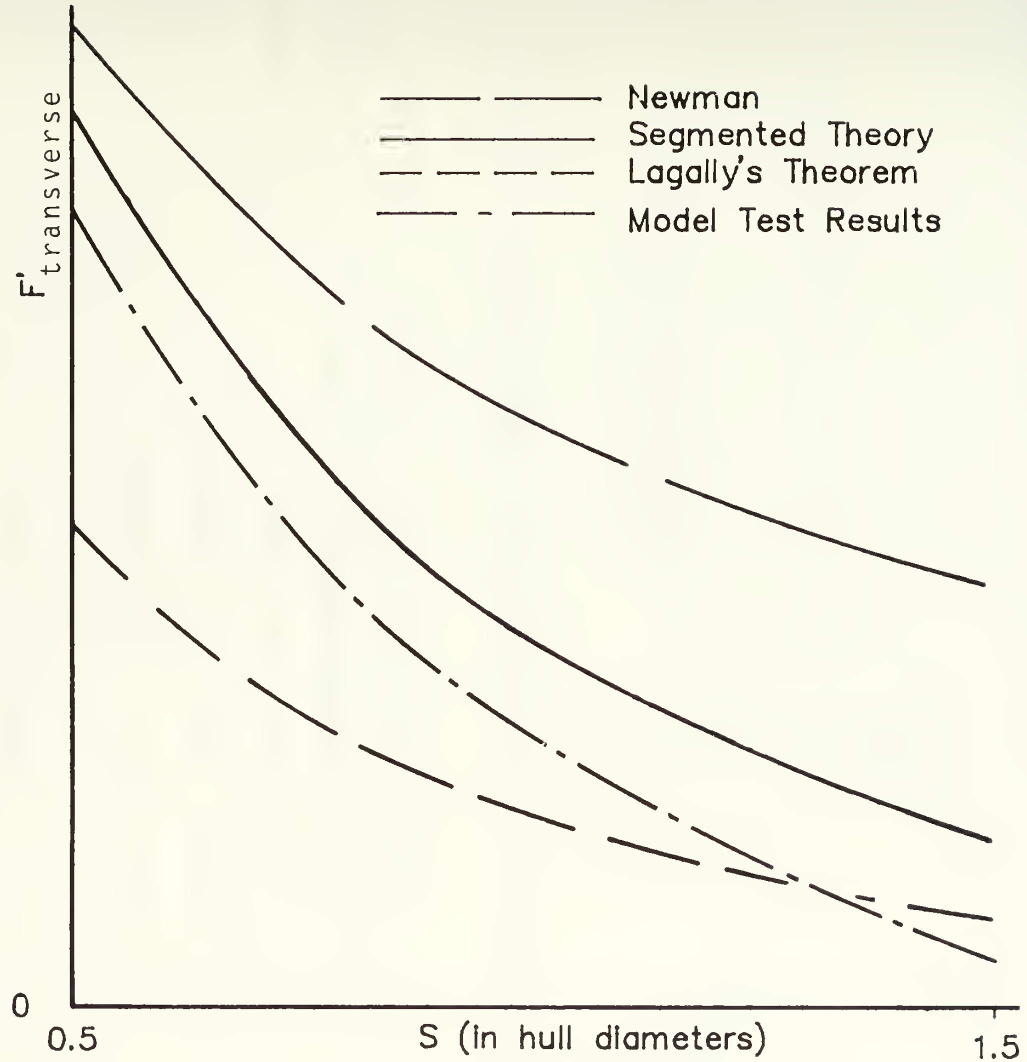

Figure 8. The Transverse Force Acting on a Modern Submarine Hull Form in the Vicinity of a Flat Wall: Model Test Results Compared with Theoretical Calculations.

CHAPTER THREE

SINUSOIDAL WALL ANALYSIS

For a flat wall, the boundary condition of zero normal flow is satisfied exactly by using the method of images. However, this technique cannot be used if the wall is not flat.

Consider the case of two axisymmetric slender bodies alongside one another as shown in Figure 9 in which one body is very "large" in comparison with the other.

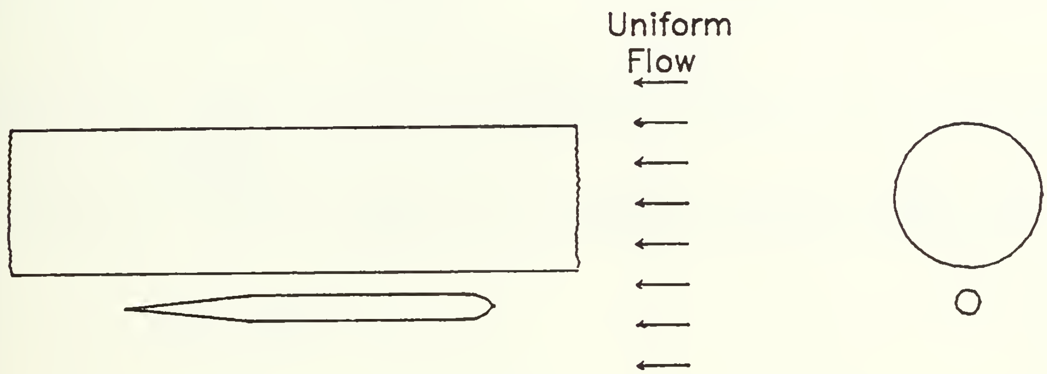

FIGURE 9: Small Body in Proximity of a Large Body Representing a Wall

Boundary conditions over each body's surface can be met using the same slender body approximations discussed in the previous chapter to size source and dipole distributions along their axes. If the large body is in fact "large enough," then from the location of the small body, it will appear as if it is a wall. As the diameter of the large body is increased, the "wall" will flatten out as shown in Figure 10. In the limit of an infinite diameter, it will become flat in cross section. Thus, by varying the radius of the large body sinusoidally in

the longitudinal direction, a sinusoidal wall can be approximated.

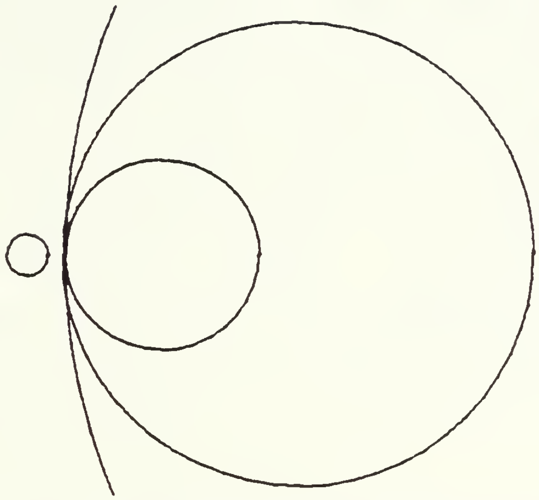

FIGURE 10: Effect of Increasing the Diameter of the Large Body

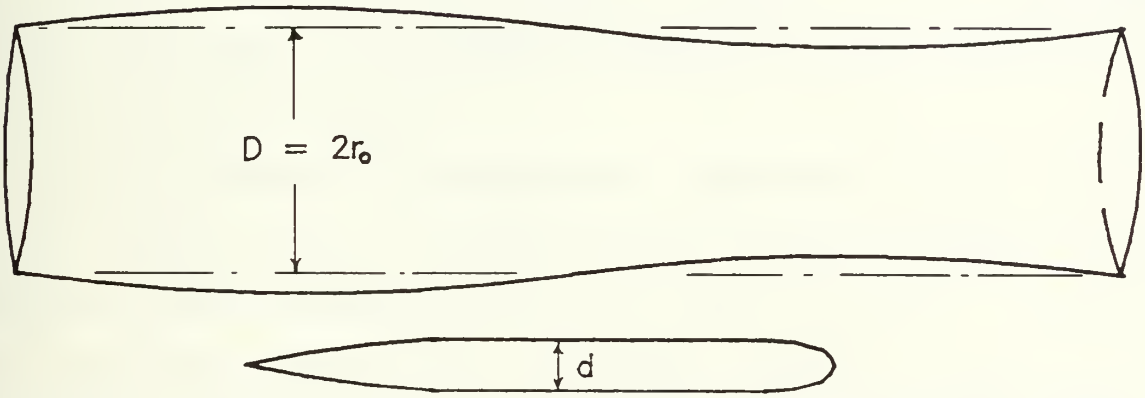

FIGURE 11: Body in Vicinity of Approximated Sinusoidal Wall

Physically, as the radius of the large body is increased and the wall becomes flatter in cross section, the force pulling the small body toward the wall should increase. If the amplitude of the wall sinusoid is zero, this force should, at a given separation distance, asymptotically approach the value obtained using the method of images.

By restricting the analysis to sinusoids with wavelengths on the order of the small body's length, and by keeping the ratio of the sinusoidal amplitude to wall wavelength "small," the slender body assumptions for the large body should be satisfied. Therefore, an axial source distribution can be sized to define the large body's shape in a longitudinal flow essentially constant along its length. The forward and after ends of the sinusoidal "wall" body are considered to be out of proximity of the small body so they have no influence on the flow between the body and wall.

A doublet distribution is superposed on the source system to counter the transverse velocity induced on the sinusoidal wall by the body. This dipole strength is proportional to the local transverse velocity.

If one defines a "significant" transverse velocity as a local velocity which is greater than, say one percent of the maximum induced transverse velocity along the wall, it can be seen that for a body in the immediate vicinity of the wall, the transverse velocity will not be significant along a length much greater than the body itself as shown in Figure 12.

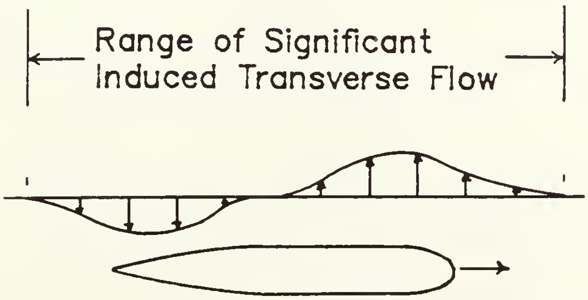

FIGURE 12: Transverse Velocity Induced on a Wall by a Body in Close Proximity

The range of significant transverse flow can be viewed as the "effective" length of the large body from a dipole sizing standpoint since the doublet strength is essentially zero outside this region. This effective length is constant for a given body at a given distance from the wall. However, as the body is moved away from the wall, the effective length increases since the maximum transverse velocity decreases much more rapidly with separation distance than do the lesser transverse velocities some longitudinal distance away.

A basic assumption in sizing the dipole distribution is that the large body is slender. Therefore, if the effective length of the sinusoidal wall is fixed, then its diameter cannot be increased without bound. Because there is no clear limit as to when a body is no longer slender, a scheme had to be devised to allow the large body's diameter to be as large as possible to obtain the best approximation of a wall, though still remain "slender."

If the amplitude of the sinusoidal wall is zero, then it is, in fact, a large cylinder modeled using only a doublet distribution in a transverse flow field. In performing calculations, it was found that as the diameter of the large cylinder was increased, the force on the small body generally grew until it reached approximately the flat wall limit obtained using the method of images. Upon increasing this diameter further, the force actually decreased, indicating that the "effective" body was no longer "slender." By using the

largest diameter for which the large body is still slender, the best approximation of a wall is obtained. Of course, this diameter increases as the body is moved away from the wall. Table 1 lists, over a range of separation distances from one-half to five body diameters, the approximate maximum "wall" diameter for which the "effective" body is still slender.

Thus, the velocity potential for the case of a body in proximity of a sinusoidal wall can be found by sizing singularity distributions for two axisymmetric bodies. Only the quasistatic case is to be analyzed, that is, the body and "wall" are held fixed in a uniform stream. Therefore, since both are axisymmetric slender bodies, their singularity systems can be sized using the same method discussed in the previous chapter and presented in Appendix B. The body shape is that of a modern submarine hull form; the "wall" shape is that of a body of revolution with its radius varying sinusoidally about a mean radius r_0 in the longitudinal direction (Figures 11 and 13). Appendix E describes the wall shape in more detail.

In the case of a sinusoidal wall, an axial force on the body is expected, unlike the flat wall situation. This axial force, the transverse force, and yaw moment can be determined using Lagally's theorem (Appendix C) once the velocity potential has been established. Similarly, the transverse force and yaw moment can be found using a segmented theory analysis (Appendix D).

TABLE 1: Maximum Diameter for Which The Sinusoidal "Wall" Body is Still Slender

SEPARATION DISTANCE, S (in terms of hull diameter, d)	DIAMETER OF LARGE "WALL" BODY, D (in terms of d)
.5	6
1	8
2	10
3	12
4	13
5	15

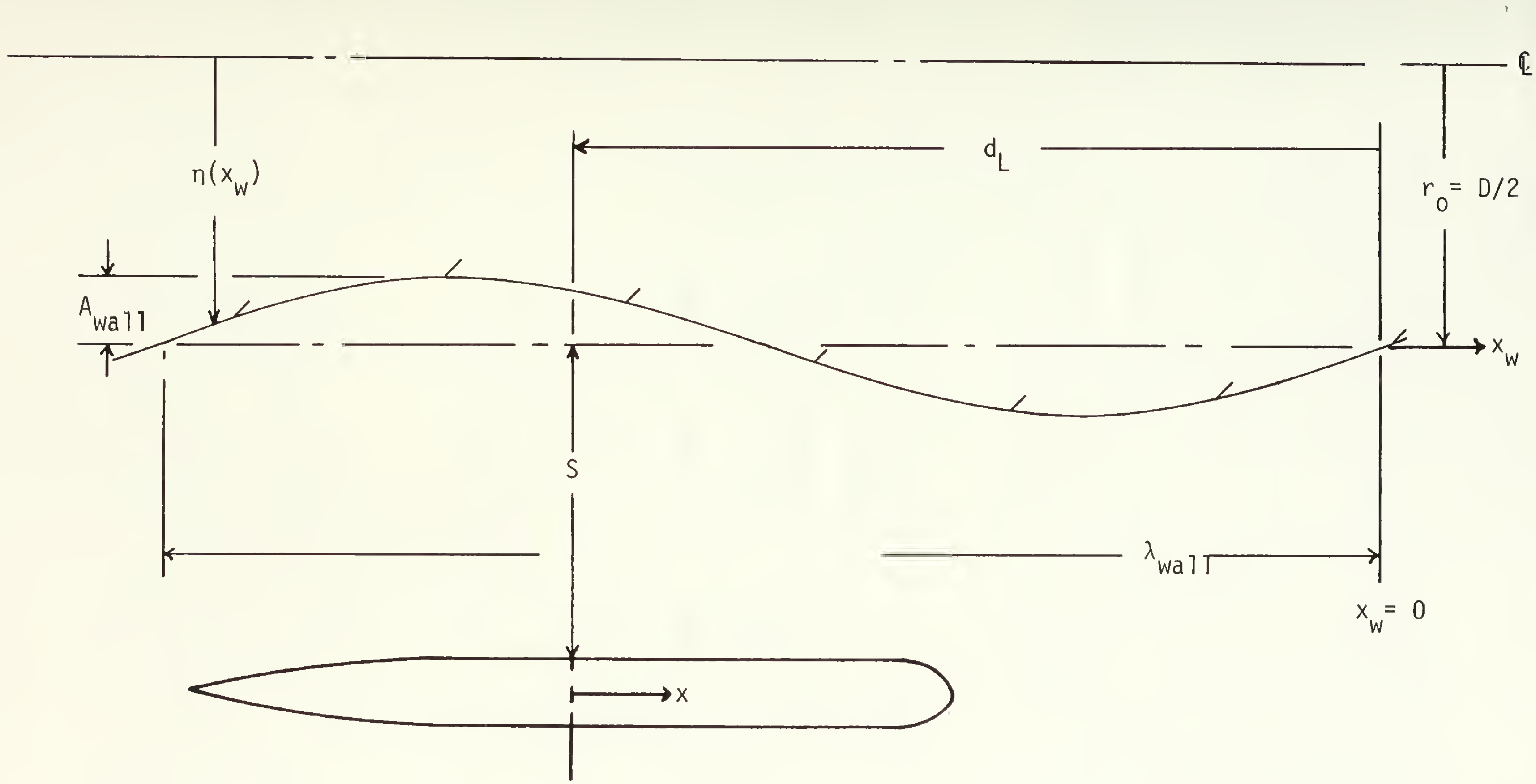

Figure 13. Sinusoidal "Wall" Body Geometry

CALCULATED RESULTS

In Figures 14 and 15, the results of calculations predicting the transverse force and moment are plotted for a modern submarine hull form near a flat wall. Results calculated using the method of images are compared against those using a sinusoidal wall with zero amplitude for both the Lagally and segmented theory techniques. The sinusoidal wall results are in agreement with those calculated using the method of images, the sinusoidal wall predictions generally being slightly less.

Figures 16 through 21 present the results calculated using Lagally's theorem for a submarine in the vicinity of a sinusoidal wall. Wall sinusoidal amplitudes, A_{wall}, are one-tenth and three-tenths of a body diameter; the wavelength, λ_{wall}, in all cases is equal to body length; separation distances, S, are spaced with one-half, one, and three body diameters between the hull and mean wall position. Values of force and moment which are negligible at a body distance of three diameters from the wall generally are omitted from the graphs presented.

Forces and moments are calculated with body position varied longitudinally while parallel to the sinusoidal wall. The longitudinal position, d_L, is defined as the axial distance between the origin of the submarine body (amidships) and the nodal point of the sinusoidal wall as shown in Figure 13.

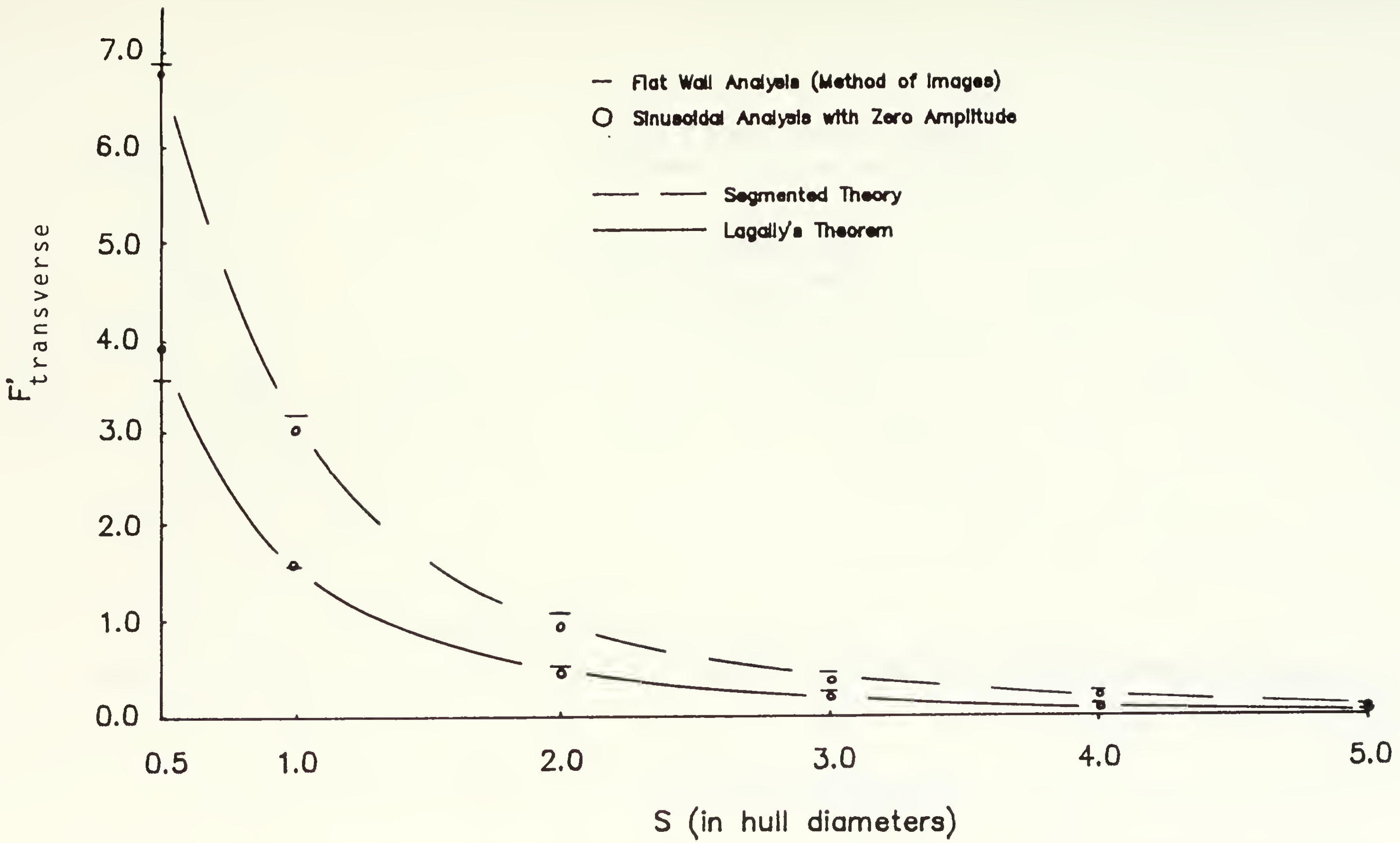

Figure 14. A Comparison Between the Transverse Force Obtained Using the Method of Images and that Using a Sinusoidal Wall Analysis with Zero Amplitude for a Modern Submarine Hull Form Traveling Near a Flat Wall

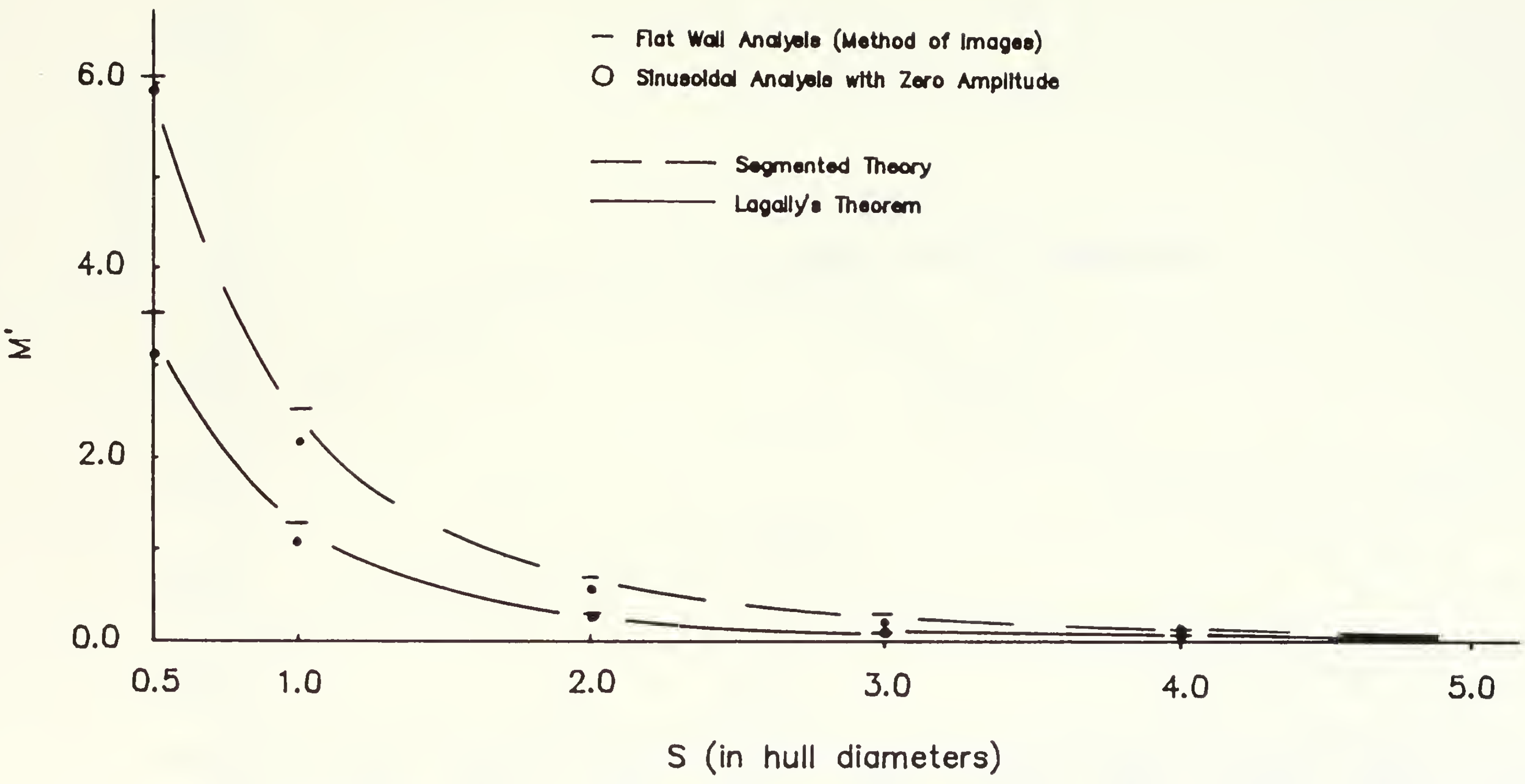

Figure 15. A Comparison Between the Moment Obtained Using the Method of Images and that Obtained Using a Sinusoidal Wall Analysis with Zero Amplitude for a Modern Submarine Hull Form Traveling Near a Flat Wall

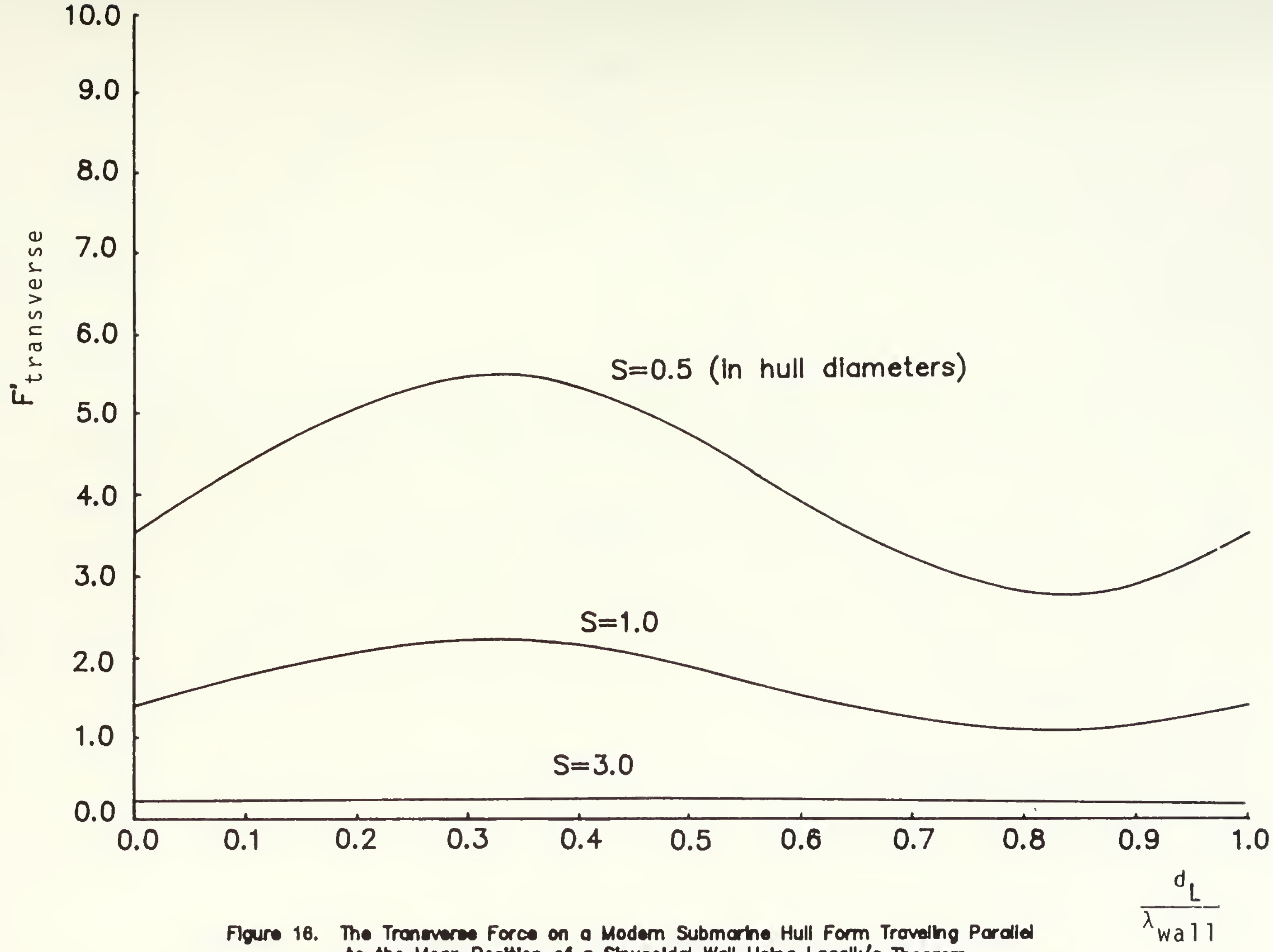

Figure 16. The Transverse Force on a Modern Submarine Hull Form Traveling Parallel to the Mean Position of a Sinusoidal Wall Using Lagally's Theorem A_{wall} =1/10 Body Diameter

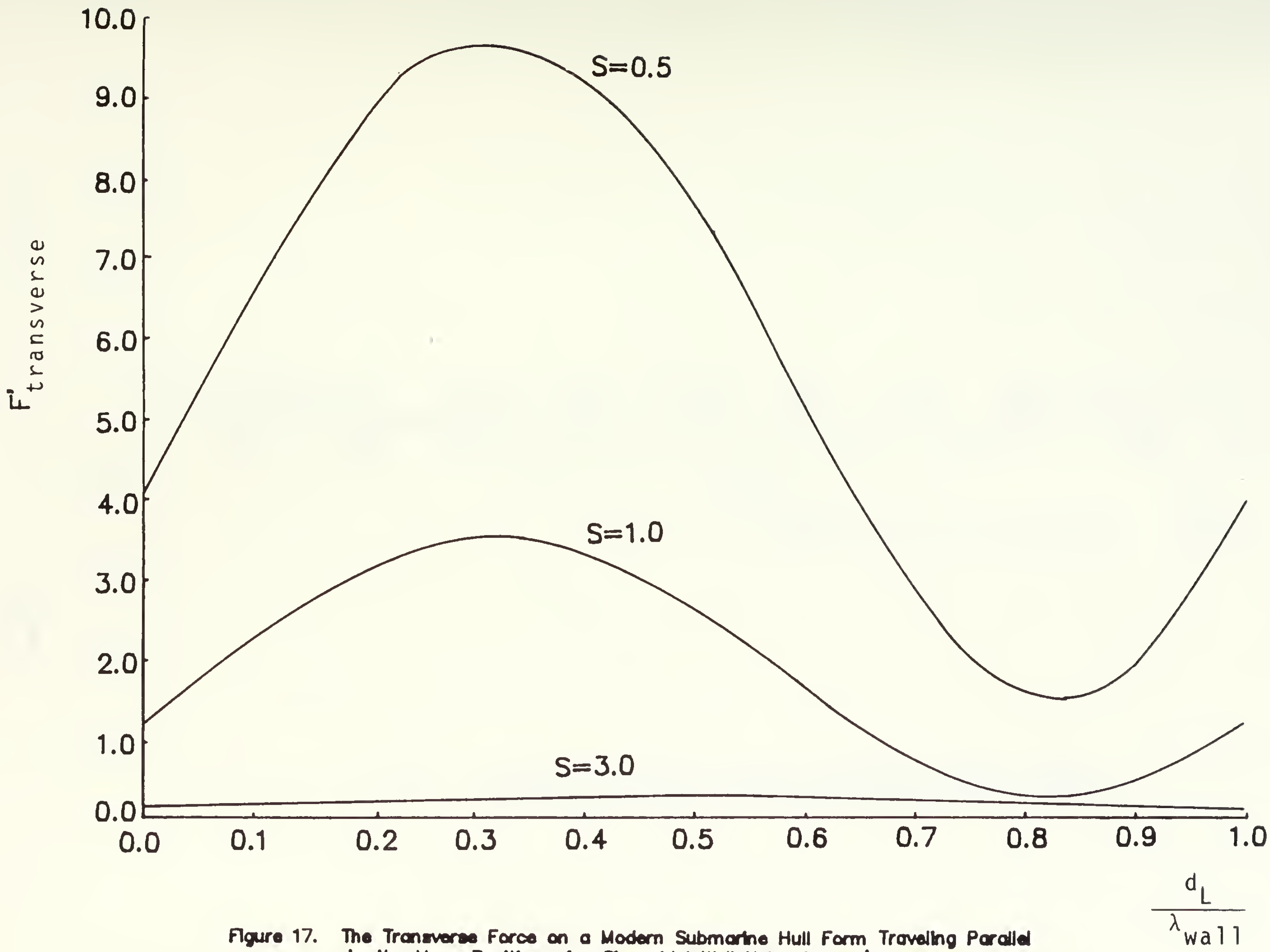

Figure 17. The Transverse Force on a Modern Submarine Hull Form Traveling Parallel to the Mean Position of a Sinusoidal Wall Using Lagally's Theorem A_{wall} =3/10 Body Diameter

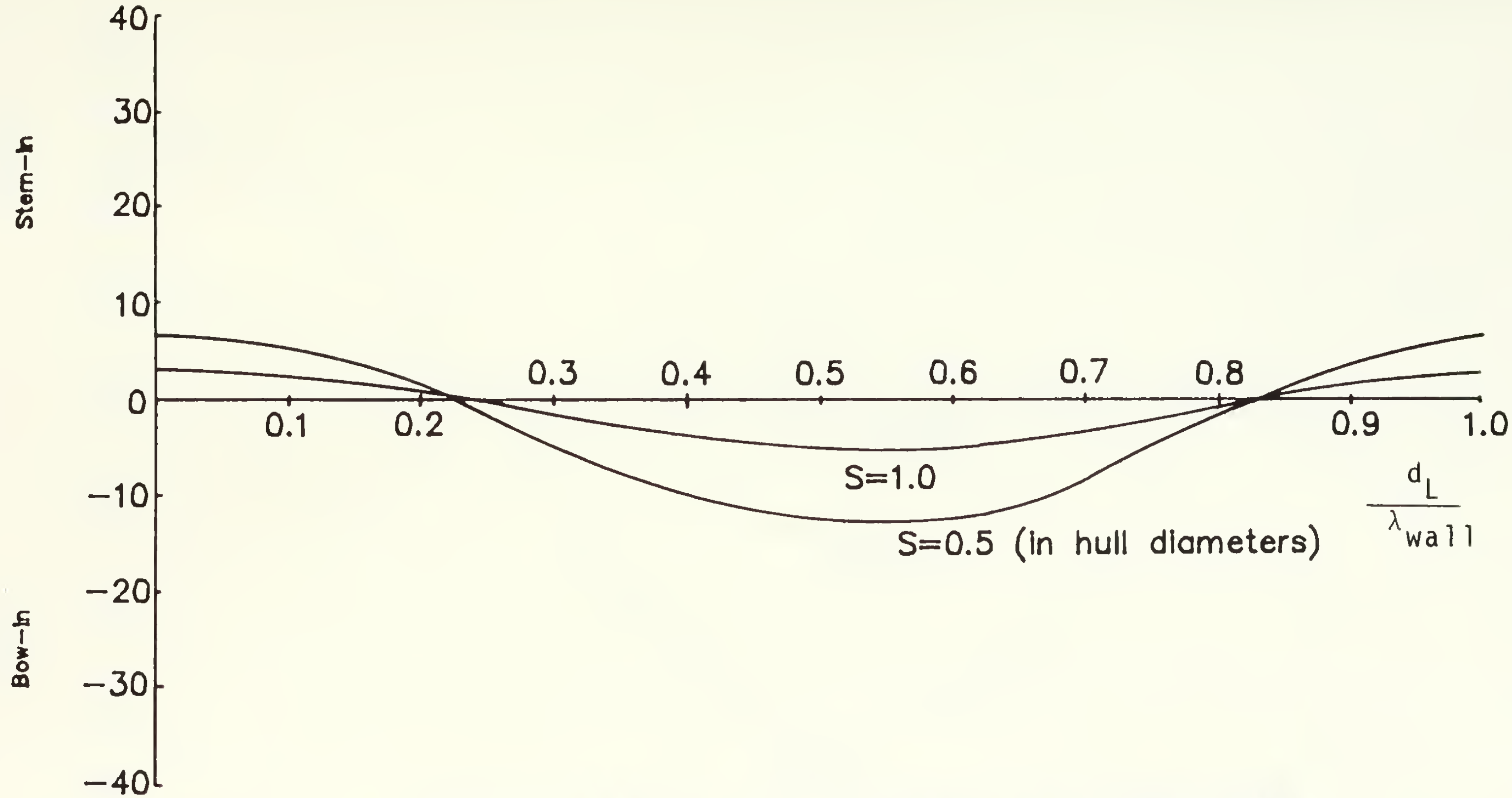

Figure 18. The Moment on a Modern Submarine Hull Form Traveling Parallel to the Mean Position of a Sinusoidal Wall Using Lagally's Theorem A_{wall} =1/10 Body Diameter

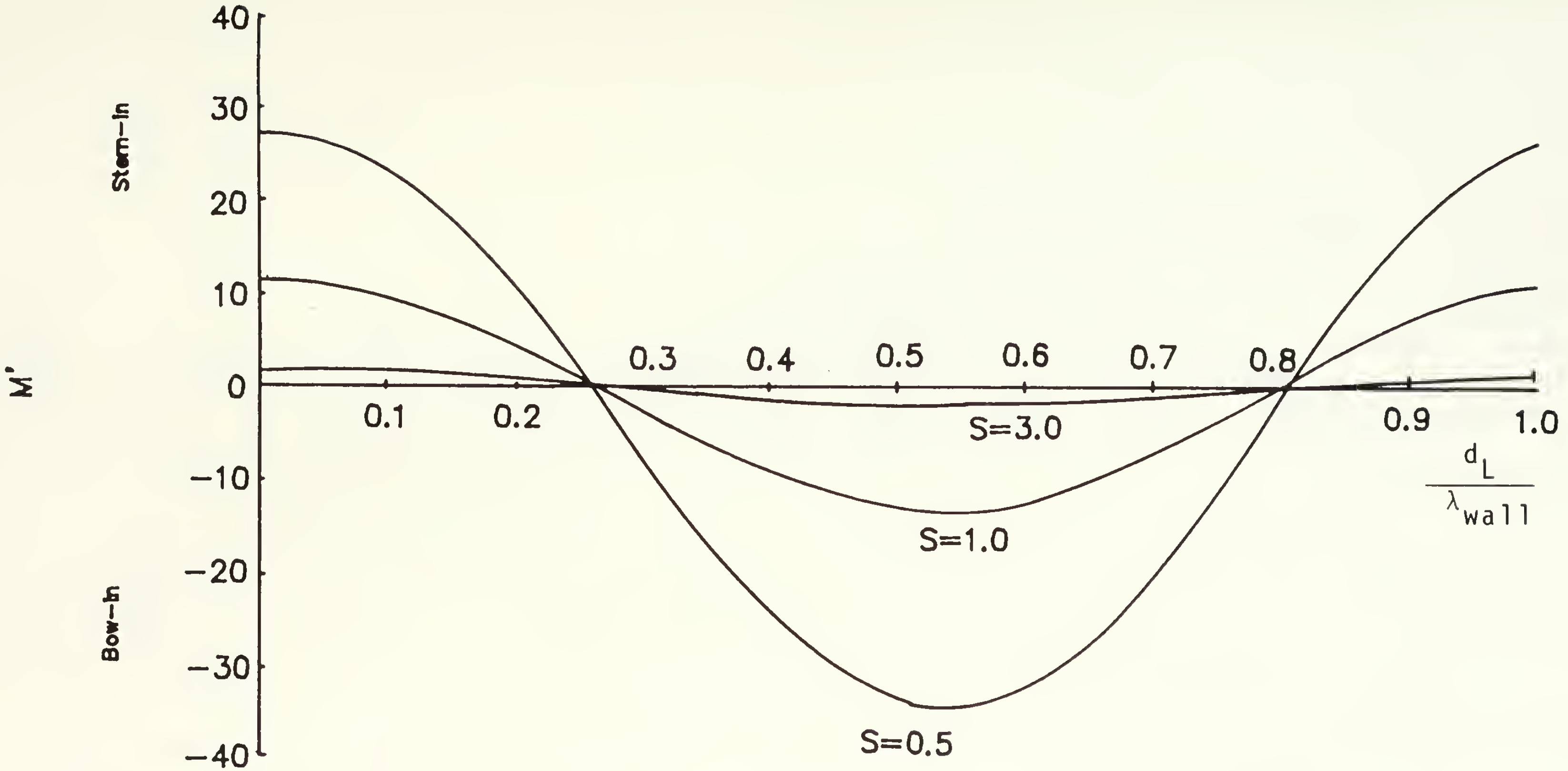

Figure 19. The Moment on a Modern Submarine Hull Form Traveling Parallel to the Mean Position of a Sinusoidal Wall Using Lagally's Theorem A_{wall} =3/10 Body Diameter

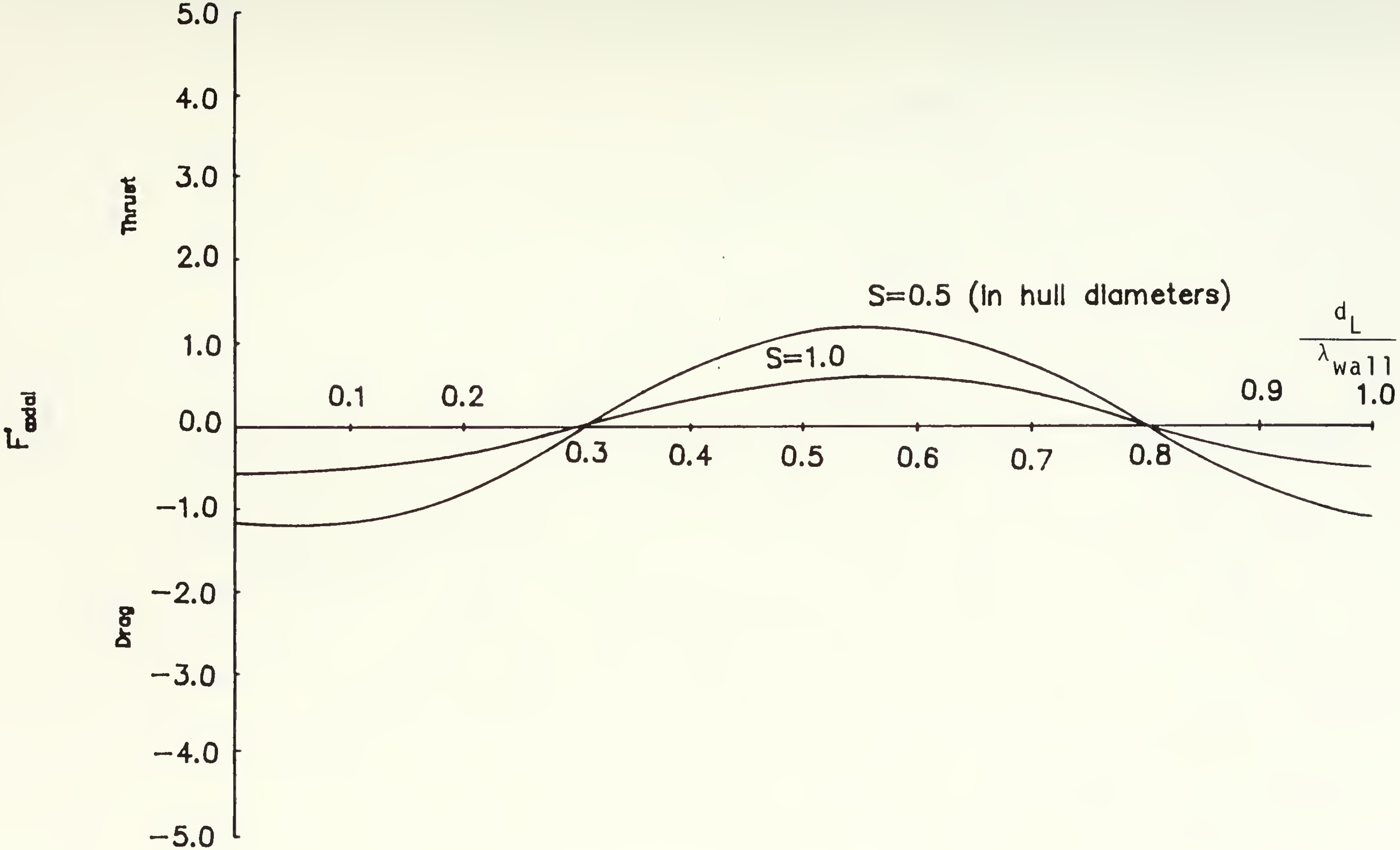

Figure 20. The Axial Force on a Modern Submarine Hull Form Traveling Parallel to the Mean Position of a Sinusoidal Wall Using Lagally's Theorem A_{wall} =1/10 Body Diameter

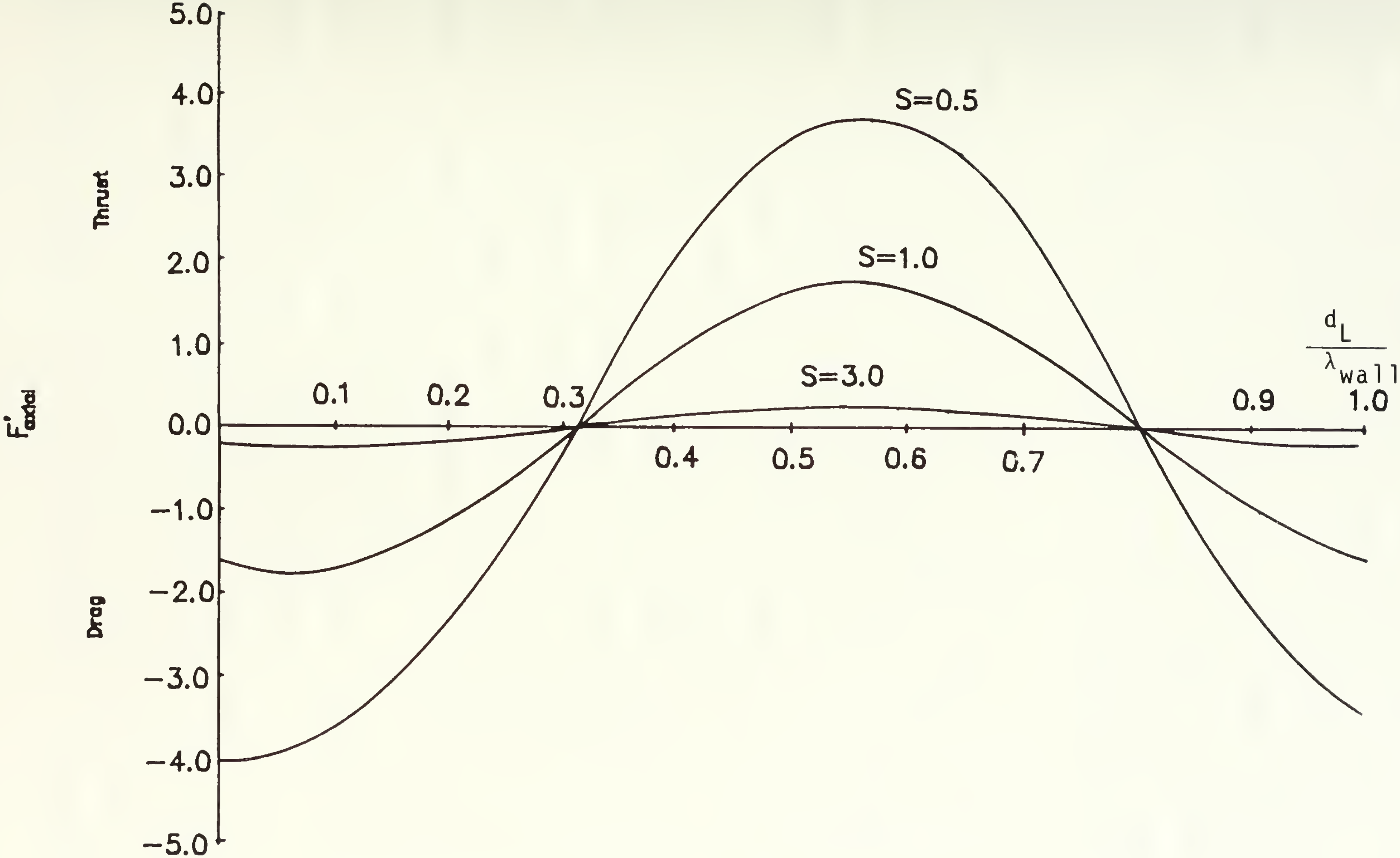

Figure 21. The Axial Force on a Modern Submarine Hull Form Traveling Parallel to the Mean Position of a Sinusoidal Wall Using Lagally's Theorem A_{wall} =3/10 Body Diameter

Forces and moment are shown to vary approximately sinusoidally with longitudinal position of the body along the wall. As the amplitude of the wall is increased by a factor of three, from one to three-tenths of a body diameter, the amplitudes of the transverse attraction force, yaw moment and axial force increase by approximately the same factor. As expected, forces and moment decrease rapidly with separation distance.

Plotted in Figures 18 and 19 are the calculated moments corresponding to the forces presented in Figures 16 and 17. The moments are 90° out of phase with the corresponding forces. "Stern-in" moments are developed as well as "bow-in" moments.

Near a flat wall, a "bow-in" moment is always predicted for a modern submarine hull form traveling in a direction parallel to the wall. This is because bow and stern are equidistant from the wall surface and since flow is accelerated much more at the bow than at the stern, the attraction force forward overshadows the force aft, resulting in a "bow-in" moment. However, for a sinusoidal wall, if the wall surface is closer to the stern than to the bow, the attraction force acting on the after section can become greater than that forward, creating a net "stern-in" moment.

An axial force is expected on a body near a sinusoidal wall since the wall surface is not parallel to the direction of body motion. The attraction force acting on the body due to a differential length of wall surface can be decomposed into

transverse and longitudinal components. The axial force, shown in Figures 20 and 21, is 180^0 out of phase with the moment and alternates between providing forward thrust and adding drag force to the body, depending on the longitudinal location of the body with respect to the sinusoidal wall.

The magnitude of this axial force is of the same order as that of the real fluid drag (F'_{drag} = 4.7) indicating that at high speed, a vessel might have difficulty maintaining velocity constant while under the influence of such a sizable oscillating axial force.

Figures 22 - 25 show the transverse force and yaw moment which result from segmented theory calculations. Segmented theory results are compared with Lagally's theorem results in Figures 26 and 27 for S = 0.5d and A_{wall} = 0.1d. Segmented theory results are similar to those calculated using Lagally's theorem with the exception that the transverse force mean value along the wall length and amplitude are approximately 3/2 times those obtained using Lagally's theorem. Also, the mean value and amplitude of the moment are approximately twice those determined using the Lagally analysis.

As previously stated, the segmented theory calculations should be more accurate than those using Lagally's theorem.

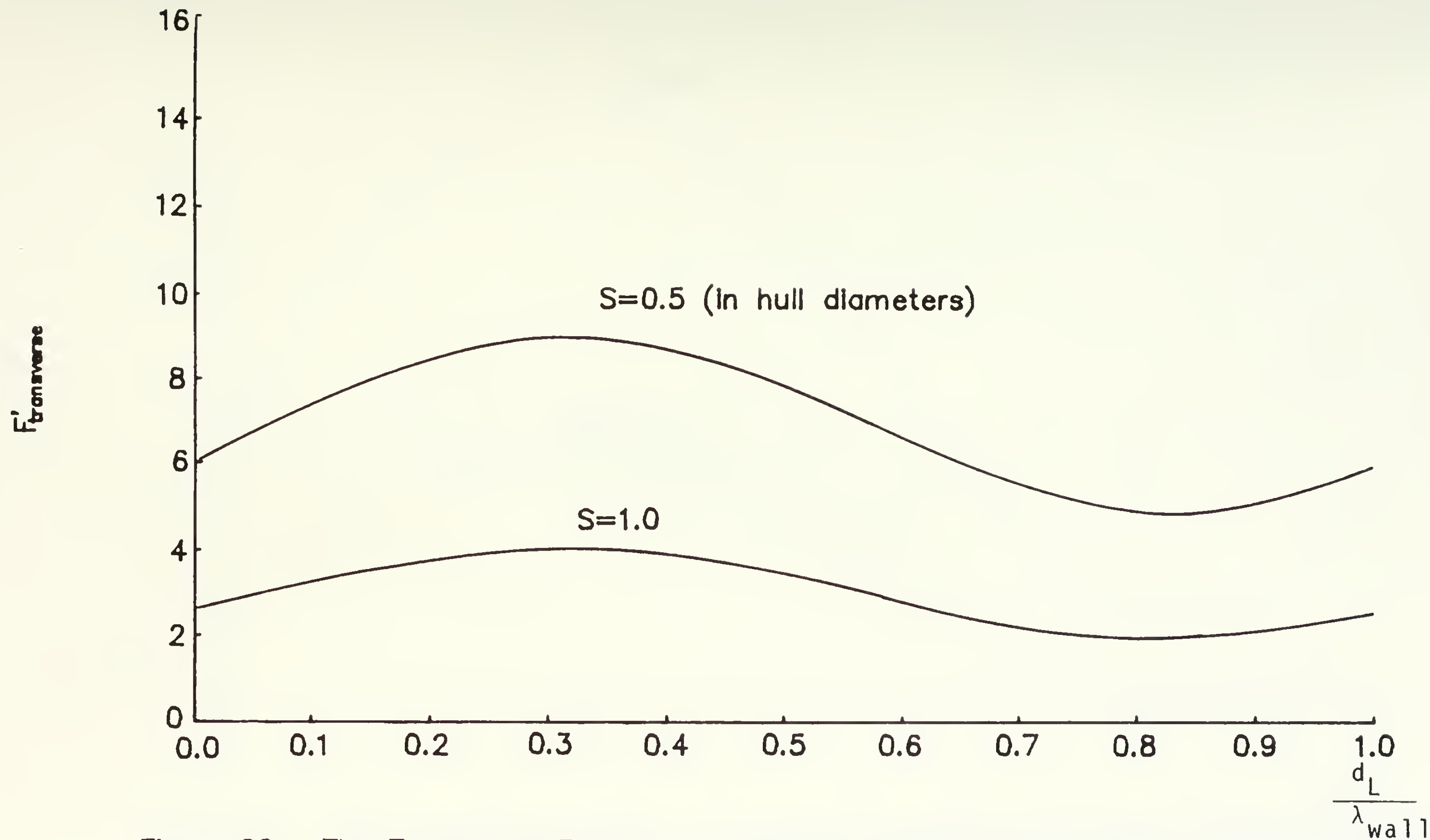

Figure 22. The Transverse Force on a Modern Submarine Hull Form Traveling Parallel to the Mean Position of a Sinusoidal Wall Using Segmented Theory A_{wall} =1/10 Body Diameter

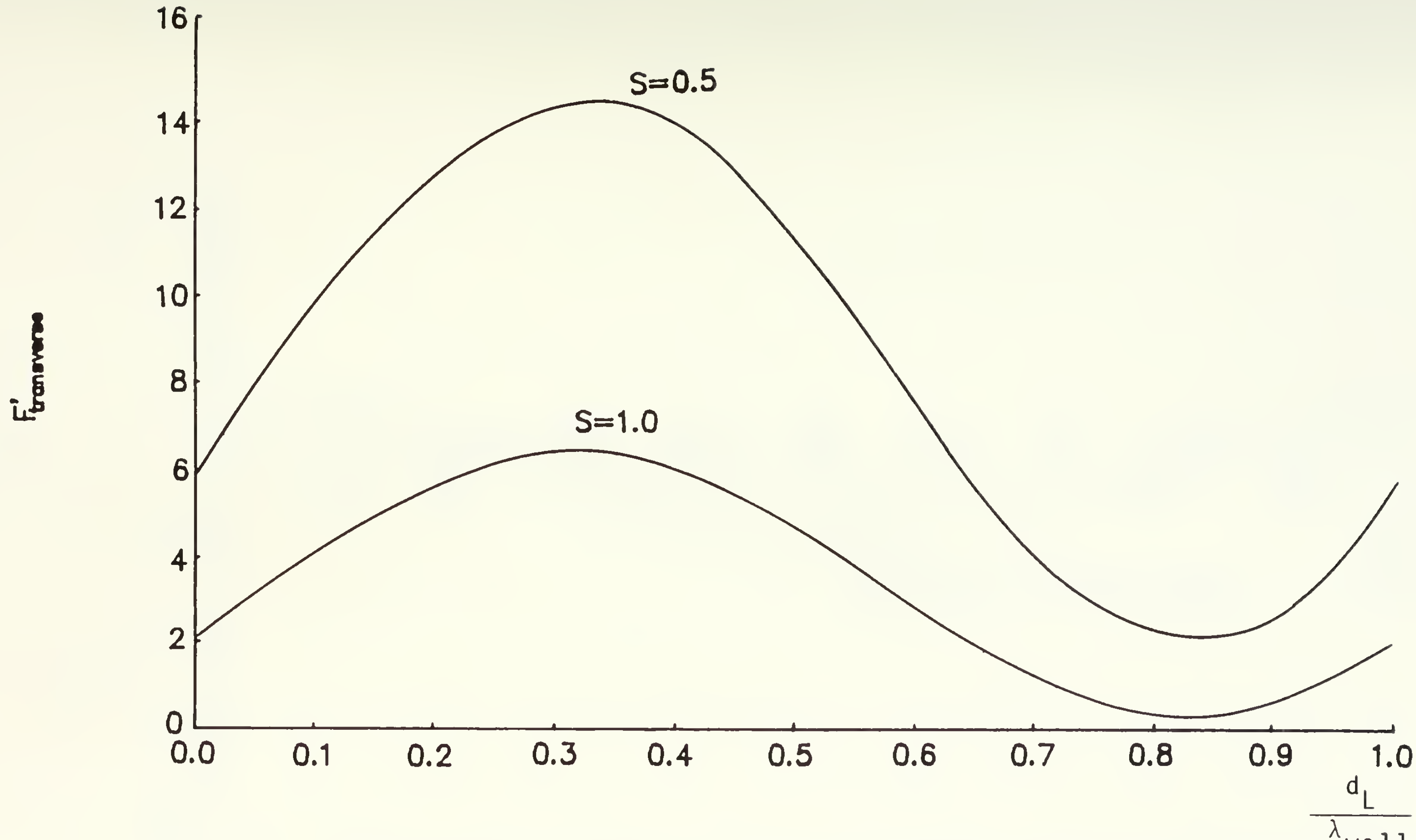

Figure 23. The Transverse Force on a Modern Submarine Hull Form Traveling Parallel to the Mean Position of a Sinusoidal Wall Using Segmented Theory A_{wall} =3/10 Body Diameter

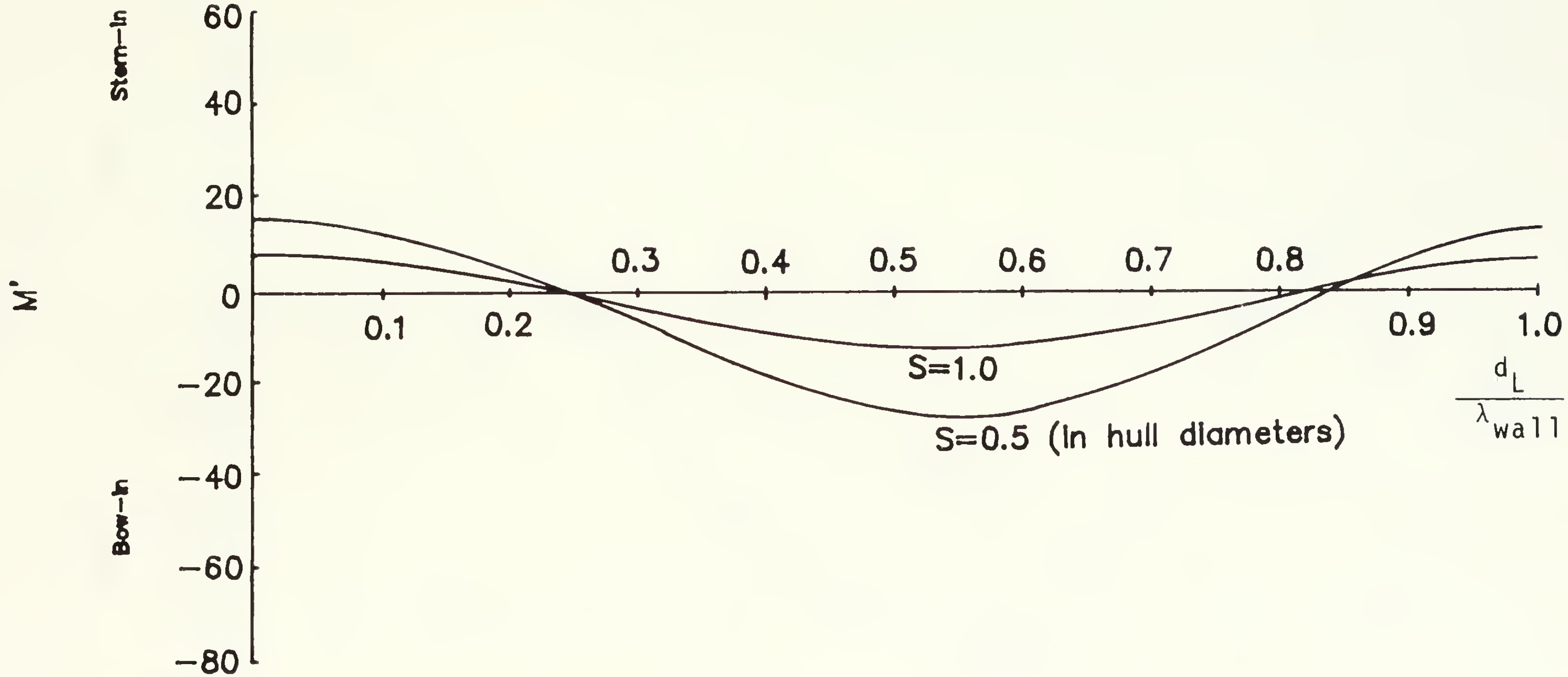

Figure 24. The Moment on a Modern Submarine Hull Form Traveling Parallel to the Mean Position of a Sinusoidal Wall Using Segmented Theory A_{wall} =1/10 Body Diameter

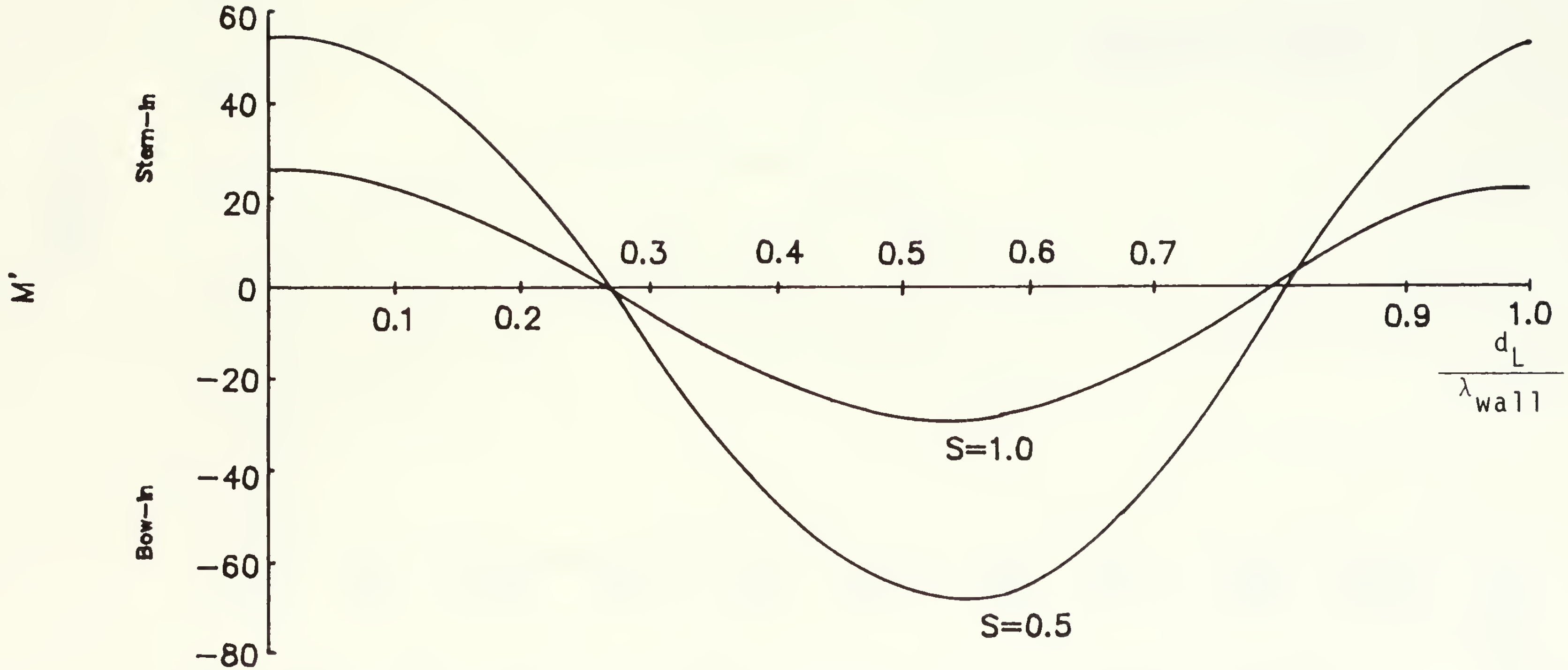

Figure 25. The Moment on a Modern Submarine Hull Form Traveling Parallel to the Mean Position of a Sinusoidal Wall Using Segmented Theory A_{wall} =3/10 Body Diameter

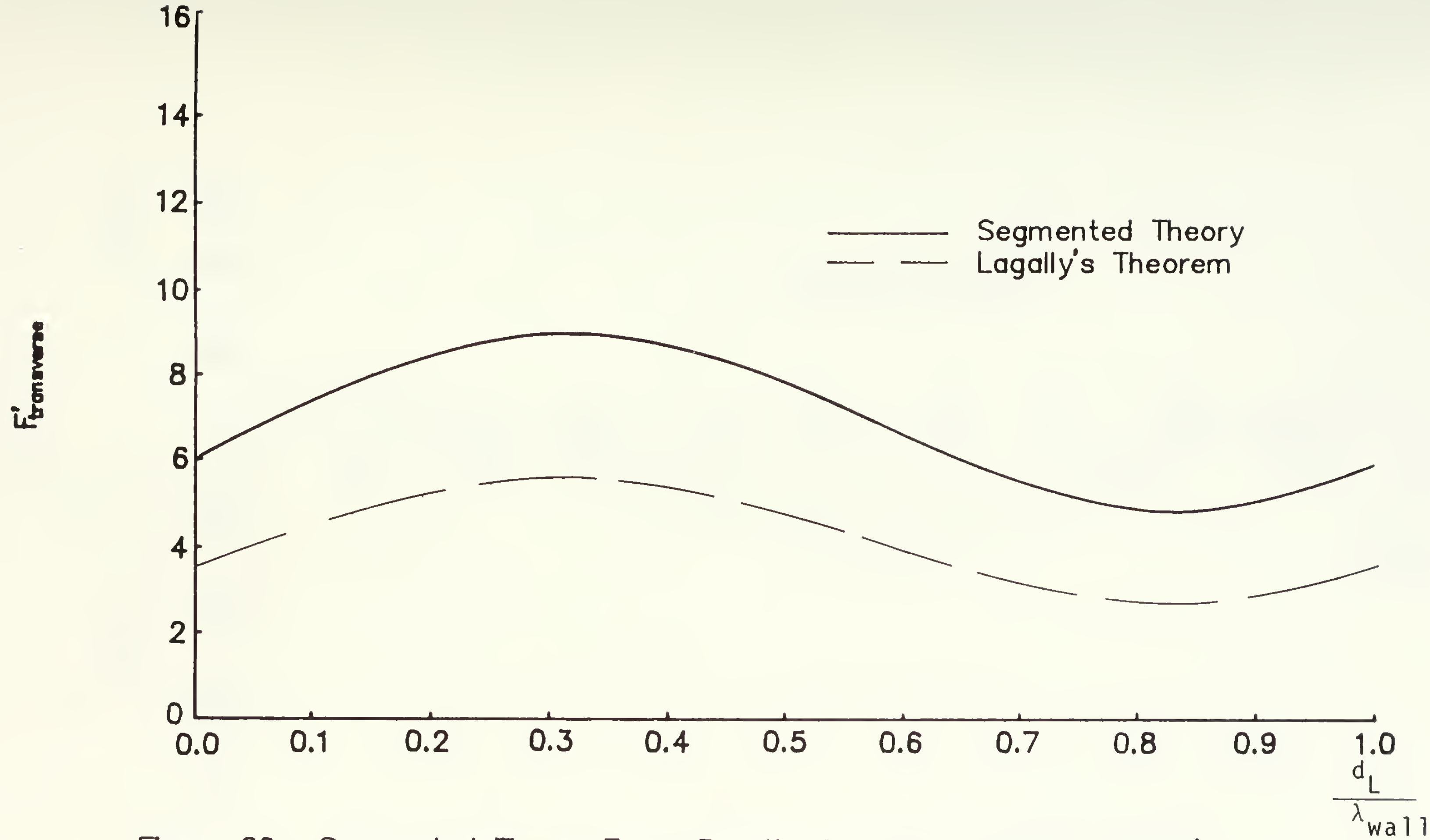

Figure 26. Segmented Theory Force Results Compared Against Lagally's Theorem Results; A_{wall} =1/10 Body Diameter, S= 5/10 Body Diameter

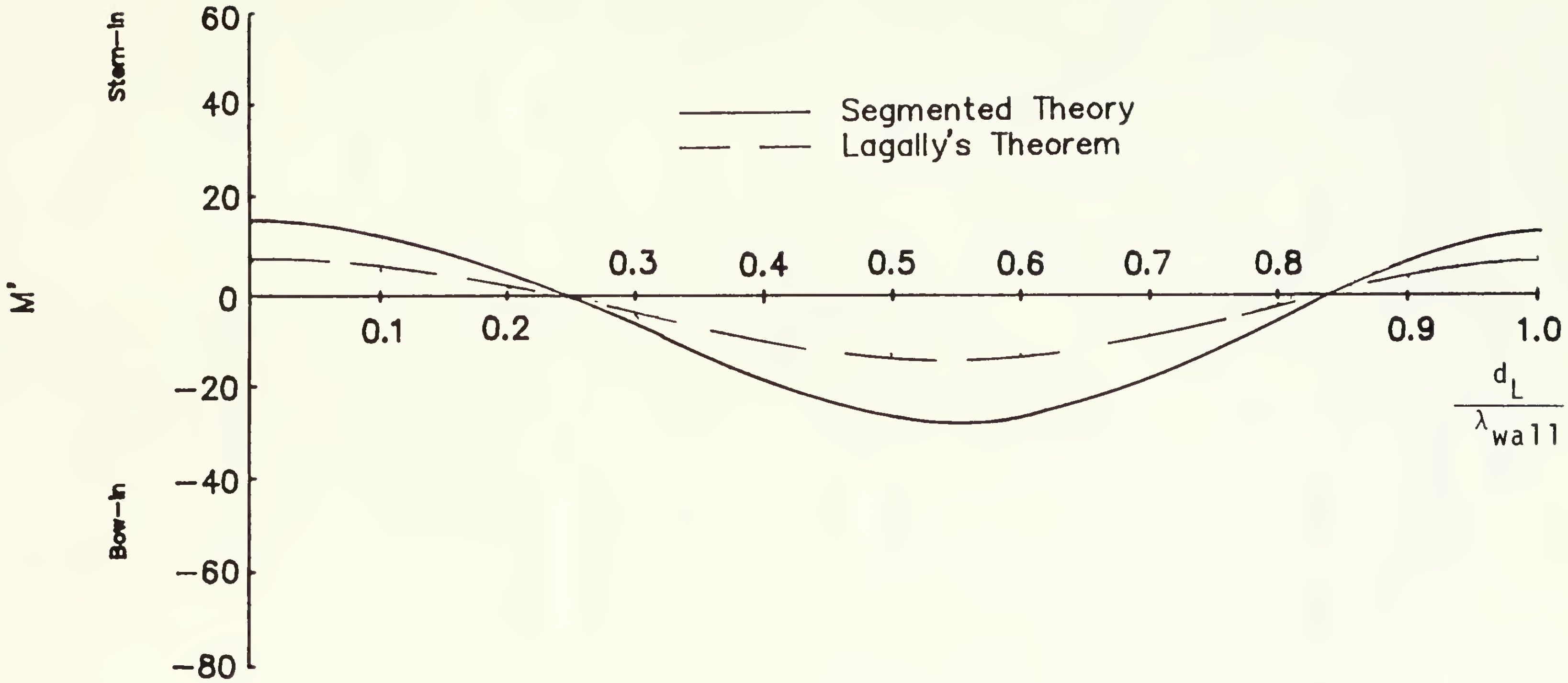

Figure 27. Segmented Theory Moment Results Compared Against Lagally's Theorem Results; A_{wall} =1/10 Body Diameter, S= 5/10 Body Diameter

CHAPTER FOUR

SUMMARY / RECOMMENDATIONS FOR FUTURE WORK

A methodology was presented for predicting the forces and moment acting on a submarine near a sinusoidal wall. Results were presented only for the case of a sinusoidal wall with wavelength equal to body length. Two interesting analyses to be investigated further are: the effect of decreasing wall wavelength and, the effect of varying the wall radius over a wide range of amplitudes. However, since a slender body approximation is used, it would be necessary to first determine how far the limits of this theory extend if wavelength is decreased for a given wall amplitude or if amplitude is increased for a given wavelength.

The purpose of modeling a sinusoidal wall was to create a basis from which to analyze the irregular wall problem. Perhaps an irregular wall can be approximated under certain circumstances using an effective equivalent combination of sinusoids. However, further investigation into the aspects of the irregular wall problem are required to determine how it might be modeled best.

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Appendix A

Hull Geometry Description of A Modern Submarine

A modern, unappended submarine's hull shape can be described most simply by dividing the body into three distinct geometries: The forebody can be approximated as an "ellipse" of revolution, the parallel midbody as a cylinder, and the after body as a "parabola" of revolution. Figure A-1 indicates these geometries.

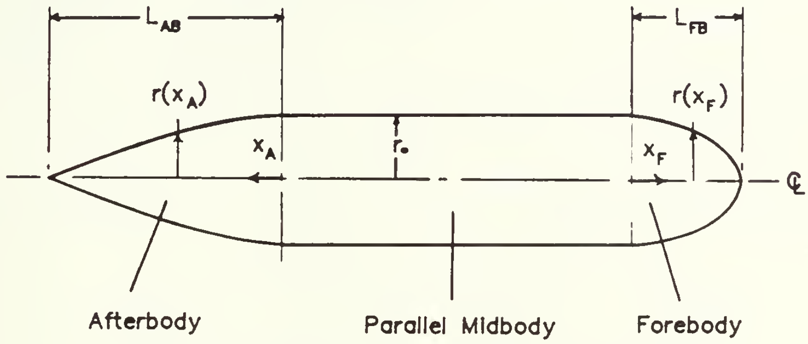

FIGURE A-1. Modern Submarine Hull Geometry

Mathematically, the radii along the length can be described as:

Forebody: $$r(x_F) = r_0\left[1 - \left(\frac{x_F}{L_{FB}}\right)^{N_F}\right]^{1/N_F} \quad (A.1)$$

Parallel midbody: $$r(x) = r_0 \quad (A.2)$$

Afterbody: $$r(x_A) = r_0\left[1 - \left(\frac{x_A}{L_{AB}}\right)^{N_A}\right] \quad (A.3)$$

"N_F" and "N_A" are commonly referred to as fullness factors and describe the degree of fullness of the fore and after sections respectively.

The slopes of the hull along the length of each section can be determined by differentiating equations (A.1) to (A.3) with respect to the appropriate x coordinate:

Forebody: $$\frac{dr(x_F)}{dx_F} = - r_0\left(\frac{1}{L_{FB}}\right)^{N_F} (x_F)^{N_F - 1} \left[1 - \left(\frac{x_F}{L_{FB}}\right)^{N_F}\right]^{\left(\frac{1}{N_F} - 1\right)} \qquad (A.4)$$

Parallel midbody: $$\frac{dr_0}{dx} = 0 \qquad (A.5)$$

Afterbody: $$\frac{dr(x_A)}{dx_A} = \frac{-N_A r_0}{(L_{AB})^{N_A}} x_A^{N_A - 1} \qquad (A.6)$$

Appendix B

Modeling An Axisymmetric Slender Body

The flow around a slender body of revolution moving with forward velocity U in an infinite ideal fluid can be approximated using a continuous axial source distribution superimposed on the velocity of a uniform stream.

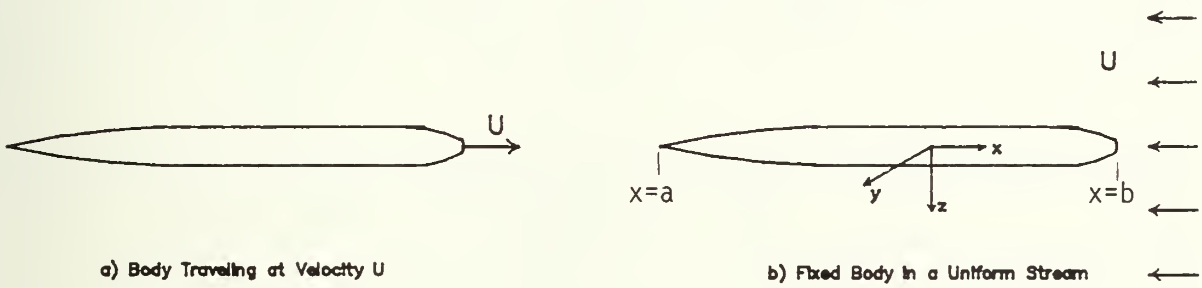

FIGURE B-1.

If the body geometry is described as:

$$r = f(x)$$

where r is the body radius, then the combined velocity potential of source distribution and free stream is:

$$\phi(x) = -Ux + \int_a^b \frac{m(\xi)}{[(x-\xi)^2 + r^2]^{1/2}} \, d\xi \qquad (B.1)$$

where U is the free stream velocity, a and b are the body endpoints as shown in Figure B-1, and $m(\xi)$ is the source strength at an axial position represented by the "dummy" variable ξ. The body oriented orthogonal axes x,y and z are defined in Figure B-1 with the origin at the midships position

along the centerline of the body.

The radial velocity with respect to the body oriented axes, $q_{radial}(x)$, can be determined to be:

$$q_{radial}(x) = -\frac{d\phi}{dr} = \int_a^b \frac{m(\xi) r \quad d\xi}{[(x-\xi)^2 + r^2]^{3/2}} \tag{B.2}$$

which can be rewritten as:

$$q_{radial}(x) = \frac{1}{r} \int_{\frac{(a-x)}{r}}^{\frac{(b-x)}{r}} \frac{m(\xi)}{[(\frac{\xi-x}{r})^2 + 1]^{3/2}} d(\frac{\xi-x}{r}) \tag{B.3}$$

For slender bodies of which $\frac{r}{L} << 1$, where L is the body length, the term $[\frac{\xi - x}{r}]^2 >> 1$ except in the vicinity of $\xi = x$. Therefore, $m(\xi)$ can be replaced by $m(x)$ and the integral limits extended to $-\infty$ to $+\infty$. Substituting $\eta = \frac{\xi - x}{r}$, equation (B.3) can be rewritten as:

$$q_{radial}(x) = \frac{m(x)}{r} \int_{-\infty}^{\infty} \frac{d\eta}{(\eta^2 + 1)^{3/2}} = \frac{m(x)}{r} \tag{B.4}$$

Since the body is slender, $q_{radial}(x)$ can also be approximated to first order as

$$q_{radial}(x) = U \frac{df(x)}{dx} \tag{B.5}$$

because the velocity in the x direction is essentially U along the body side.

Equating equation (B.4) with (B.5),

$$\frac{m(x)}{r} = U \frac{df(x)}{dx} . \tag{B.6}$$

Therefore, the source strength must be:

$$m(x) = Ur(x) \frac{dr(x)}{dx} \tag{B.7}$$

An axisymmetric body moving steadily along its axis in an infinite inviscid and irrotational fluid experiences absolutely no hydrodynamic forces. However, if singularities external to the body are introduced into the fluid field, then forces will act on the body. These forces can be determined using Lagally's theorem or segmented theory if the internal and external singularities are known.

When the axial distribution of sources is brought into the proximity of other singularities external to the body of revolution, velocities will be induced on the body surface which will disturb the satisfaction of the surface boundary conditions previously employed. In order to re-establish the body surface boundary conditions, it is usually necessary to introduce additional singularity distributions into the body which are images of the externally induced flow. These image distributions can be sized exactly only for spheres. However, for slender bodies, an approximate singularity distribution can be determined.

Consider the case of two geometrically similar bodies of revolution of equal size moving parallel to one another along their axes with constant velocity U.

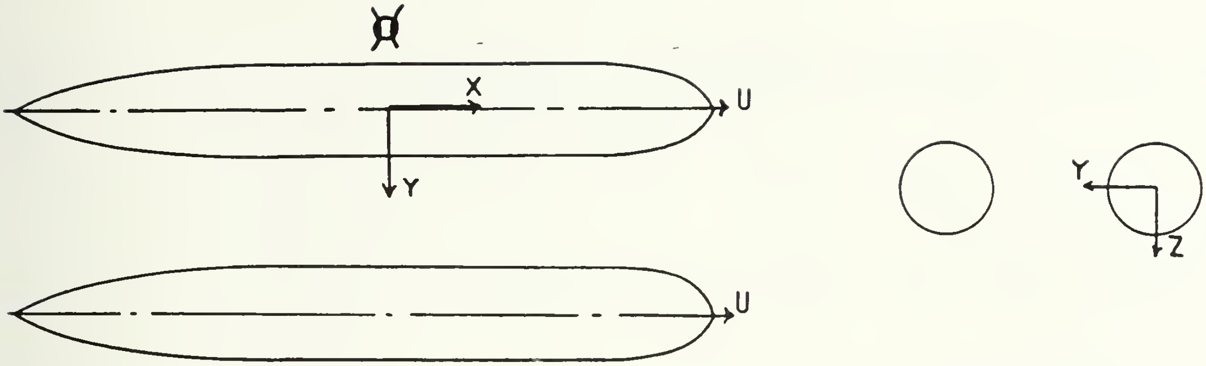

FIGURE B-2 Two Geometrically Similar Bodies of Revolution Moving Parallel to One Another.

Each body alone in an infinite fluid can be modeled as a continuous source distribution using equation (B.7), however, when two bodies are placed in proximity, velocities induced on each body by the other will distort their shapes.

Consider now the transverse velocity induced on one body. Since this body is slender, it is reasonable to assume that over any short axial length, the transverse velocity which would exist if the body were not present is approximately uniform. An axial distribution of doublets can be sized which will counter this cross flow velocity and restore satisfaction of the boundary conditions.

Since this analysis is restricted to slender bodies, it can be further assumed that the body will be cylindrical over any small change in axial location. Therefore, the image axial dipole distribution can be sized using two dimensional theory.

For a cylinder of infinite length in a uniform transverse flow, its velocity potential may be expressed as:

$$\phi(x) = \int_{-\infty}^{\infty} \frac{\zeta\, y}{r^3}\, d\xi \qquad \text{(B.8)}$$

where ζ is the strength of the axial distribution of doublets, constant along the infinite cylinder's length; y and r are,

respectively, the transverse and radial distances from the axis. This expression is valid if

$$\zeta = \frac{1}{2} R^2 V, \tag{B.9}$$

where R is the radius of the cylinder and V is the uniform, transverse velocity.

Treating the slender axisymmetric body as a piecewise summation of cylindrical components, the image doublet distribution strength will be:

$$\zeta(x) = \frac{1}{2} r^2(x) v(x) \tag{B.10}$$

where $\zeta(x)$, $r(x)$ and $V(x)$ now vary along the body length. This approximation is good provided the slope of the body is not too large; near the blunt forward end of a modern submarine, this approximation is very poor.

The situation of two bodies of equal size moving parallel to one another as shown in Figure B-2 can be considered as the case of a body and its image. In this situation, due to the symmetry of flow about the x-y plane, the dipole distribution oriented in the z direction, $\zeta_z(x)$, will be zero along the entire body length.

The induced longitudinal velocities $u(X)$ can be accounted for by resizing the axial source strengths accordingly, that is,

$$m(x) = -\frac{(u(x) - U)}{2} r(x) \frac{dr(x)}{dx} \tag{B.11}$$

However, induced longitudinal velocities will generally be insignificant when compared with the free stream velocity.

Shifting this analysis to the image body, it can be seen that the image has velocities induced on it which are caused by the resized source and newly introduced doublet distributions of the body which will, in turn, disturb the image body boundary conditions. However, by iterating this procedure of resizing the singularities on each body, convergence can be obtained and, ultimately, all boundary conditions satisfied (Reference 3).

Appendix C

Determining the Force and Moment on An Axisymmetric Body Using Lagally's Theorem

The Lagally Force and Moment

After having obtained the velocity potential description for a body in the vicinity of a wall, the pressure distribution around the body can be obtained using Bernoulli's Theorem. By integrating this pressure over the body surface, the force and moment acting on the body can also be determined.

However, if the body is modeled as an axial distribution of discrete sources and doublets, the force and moment acting on each singularity will be a function of the singularity type and strength as well as the velocity induced at its location by all singularities external to the body. By summing up the force and moment due to each singularity within the body, the total force and moment can be determined. Since in fact the body is represented by a continuous axial distribution of sources and doublets, the summation becomes an integration of differential forces and moments along the axis.

Lagally was the first to reason this approach and derived simple expressions which relate the force and moment on a body to the singularity distribution which describes it. The Lagally force and moment are limited to steady-flow problem analyses, however, this is consistent with the constant velocity situation studied in this thesis.

The steady-state Lagally forces and moments can be expressed as:

$$\vec{F}(\xi) = -4\pi\rho[m(\xi)\vec{q}(\xi) + (\vec{\zeta}(\xi).\nabla)\vec{q}(\xi)] \tag{C.1}$$

$$\vec{M}(\xi) = \vec{r}(\xi) \times \vec{F}(\xi) + 4\pi\rho(\vec{q}(\xi) \times \vec{\zeta}(\xi)) \tag{C.2}$$

where $\vec{F}(\xi)$ and $\vec{M}(\xi)$ are the differential force and moment, respectively, acting on a source of strength $m(\xi)$ and doublet of strength $\vec{\zeta}(\xi)$ at the axial location described by the position vector $\vec{r}(\xi) = \xi\,\hat{i} + o\,\hat{j} + o\,\hat{k}$. $\vec{q}(\xi)$ is the velocity induced at the location $\vec{r}(\xi)$ by all singularities external to the body and ρ is the water density.

Decomposing equations (C.1) and (C.2) into orthogonal components:

$$F_x(\xi) = -4\pi\rho[m(\xi)\,q_x(\xi) + (\zeta_y(\xi)\,\frac{\partial}{\partial y})\,q_x(\xi)]$$

$$F_y(\xi) = -4\pi\rho[m(\xi)\,q_y(\xi) + (\zeta_y(\xi)\,\frac{\partial}{\partial y})\,q_y(\xi)]$$

$$F_z(\xi) = -4\pi\rho[m(\xi)\,q_z(\xi) + (\zeta_y(\xi)\,\frac{\partial}{\partial y})\,q_z(\xi)] \tag{C.3}$$

$$M_x(\xi) = -4\pi\rho[\zeta_y(\xi)\,q_z(\xi)]$$

$$M_y(\xi) = -\xi F_z(\xi) \tag{C.4}$$

$$M_z(\xi) = \xi F_y(\xi) + 4\pi\rho\zeta_y(\xi)\,q_x(\xi)$$

where the subscripts x, y, and z denote the respective component of force or moment. Analyzing for the case of two axisymmetric bodies moving parallel to one another in an

otherwise infinite fluid, the doublet distributions in the x and z directions, ζ_x and ζ_z are both zero along the centerlines of both bodies. Therefore, these terms have been omitted from equations C.3 and C.4.

By symmetry of the induced flow about the plane z = 0, $q_z(\xi)$ is also zero. Therefore, equations (C.3) and (C.4) can be reduced to:

$$F_x(\xi) = -4\pi\rho[m(\xi)\, q_x(\xi) + \zeta_y(\xi) \frac{\partial}{\partial y}\, q_x(\xi)]$$
$$F_y(\xi) = -4\pi\rho[m(\xi)\, q_y(\xi) + \zeta_y(\xi) \frac{\partial}{\partial y}\, q_y(\xi)] \qquad \text{(C.3a)}$$
$$F_z(\xi) = 0$$

$$M_x(\xi) = 0$$
$$M_y(\xi) = 0 \qquad \text{(C.4a)}$$
$$M_z(\xi) = \xi F_y(\xi) + 4\pi\rho\zeta_y(\xi)\, q_x(\xi)$$

Induced Velocities and Velocity Gradients

Next, in order to determine the force and moment on the body, it is necessary to develop expressions for the velocities and velocity gradients induced on the body by external singularities.

Consider the case at hand in which two bodies of revolution are moving along their axes, each parallel to the other, at constant forward velocity U, as shown in Figure C-1.

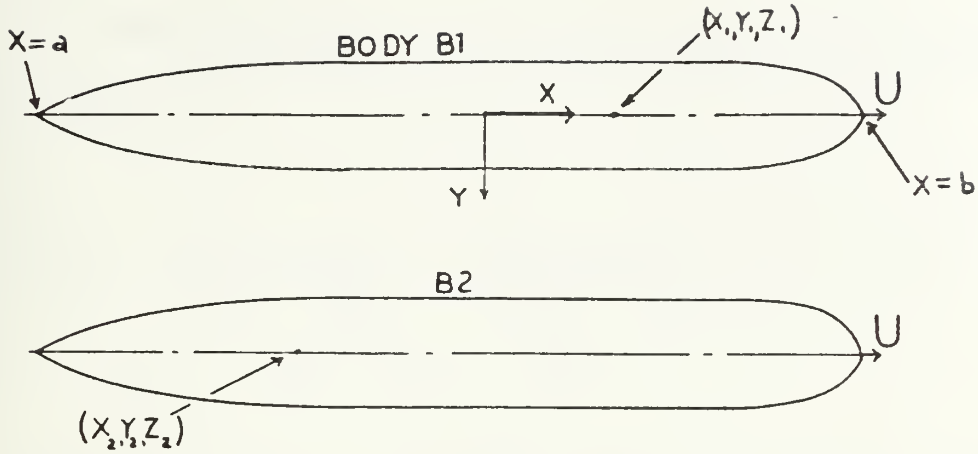

FIGURE C-1. Two Bodies of Revolution Moving Parallel To One Another at Constant Velocity U.

If the singularity distribution in body B1 is composed of an axial source distribution superimposed on a transverse dipole distribution oriented in the y direction, the potential function at a point (x_2, y_2, z_2) located in B2 due to the singularities at point (x_1, y_1, z_1) in B1 can be described as:

$$\phi(x_2,y_2,z_2) = \frac{-m(x_1,y_1,z_1)}{r_{12}} + \frac{-\zeta_y(x_1,y_1,z_1)\ (y_2 - y_1)}{r_{12}^3} \qquad \text{(C.5)}$$

where $m(x_1, y_1, z_1)$ and $\zeta_y(x_1, y_1, z_1)$ are the source strength and dipole strength respectively at the point (x_1, y_1, z_1) and

$r_{12} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$.

For the problem at hand, it is convenient and appropriate to take $y_1 = 0$ and $z_1 = 0$ since the singularity distribution is along the axis, and substitute the "dummy" variable ξ for x_1. In order to find the total velocity potential at a point (x_2, y_2, z_2) due to only the axial singularity distributions in

body B1, it is necessary to integrate equation (C.5) over the length of B1.

That is,

$$\phi(x_2,y_2,z_2) = \int_a^b \left\{ \frac{-m(\xi)}{r_{12}} - \frac{\zeta_y(\xi)\ y_2}{r_{12}^{\ 3}} \right\} d\xi \qquad (C.6)$$

where $r_{12} = [(x_2 - \xi)^2 + y_2^{\ 2} + z_2^{\ 2}]^{\frac{1}{2}}$

This integration can be performed numerically using Simpson's Rule.

Velocities induced at points located in B2 can be determined by differentiating the velocity potential and evaluating it at the desired location.

$$q_x(x_2,y_2,z_2) = \frac{\partial\phi(x_2,y_2,z_2)}{\partial x_2} = \int_a^b \left\{ \frac{(x_2-\xi)m(\xi)}{r_{12}^{\ 3}} + \frac{3(x_2-\xi)\zeta_y(\xi)y_2}{r_{12}^{\ 5}} \right\} d\xi \qquad (C.7)$$

$$q_y(x_2,y_2,z_2) = \frac{\partial\phi(x_2,y_2,z_2)}{\partial y_2} = \int_a^b \left\{ \frac{y_2 m(\xi)-\zeta_y(\xi)}{r_{12}^{\ 3}} + \frac{3y_2^{\ 2}\zeta_y(\xi)}{r_{12}^{\ 5}} \right\} d\xi \qquad (C.8)$$

Similarly, the velocity gradients $\frac{\partial}{\partial y}(q_x)$ and $\frac{\partial}{\partial y}(q_y)$ can be obtained by differentiating the velocities:

$$\frac{\partial}{\partial y}[q_x(x_2,y_2,z_2)] = \int_a^b \left\{ \frac{3(x_2-\xi)[\zeta_y(\xi)-m(\xi)y_2]}{r_{12}^{\ 5}} - \frac{15(x_2-\xi)y_2^{\ 2}\ \zeta_y(\xi)}{r_{12}^{\ 7}} \right\} d\xi \qquad (C.9)$$

$$\frac{\partial}{\partial y}[q_y(x_2,y_2,z_2)] = \int_a^b \left\{ \frac{m(\xi)}{r_{12}^{\ 3}} + \frac{3y_2[3\zeta_y(\xi)-y_2 m(\xi)]}{r_{12}^{\ 5}} - \frac{15y_2^{\ 3}\zeta_y(\xi)}{r_{12}^{\ 7}} \right\} d\xi \qquad (C.10)$$

Expressions for the differential force and moment acting along the body length can now be determined by evaluating equations (C.7-10) at a point (ξ_2,0,0) along the B2 axis, and

substituting the results into equations (C.3a) and (C.4a). (NOTE: ξ_1 and ξ_2 are introduced here to distinguish between the dummy variable ξ on body B1 and on B2.) The total force and moment acting on B2 can be determined by integrating equations (C.3a) and (C.4a) along its length.

Appendix D

The Force and Moment on an Axisymmetric Body Using Segmented Theory

If a slender axisymmetric body is maintained at constant velocity in an accelerating fluid, the lateral force on the body can be approximated using a "segmented" theory proposed by Abkowitz. "Segmented" refers to dividing the body into vertical segments and calculating the force on each segment using either a two or three-dimensional flow analysis, whichever is appropriate. In the two-dimensional case, the segments correspond to "strips" used in strip theory.

Along most of the body's length, it can be assumed that the flow is locally two-dimensional. Therefore, by dividing this portion of the body into a series of thin transverse slices, the force on each segment can be found and integrated along the body's length to determine the total force. This method of analysis assumes that the flow at any segment is independent of the flow at any other location, that is, there are no hydrodynamic interactions with any other segments along the body.

However, near the blunt bow of a modern submarine, three dimensional end effects are significant and must be taken into consideration. These end effects can be accounted for by using a three-dimensional analysis which treats the bow segment as a hemi-ellipsoid.

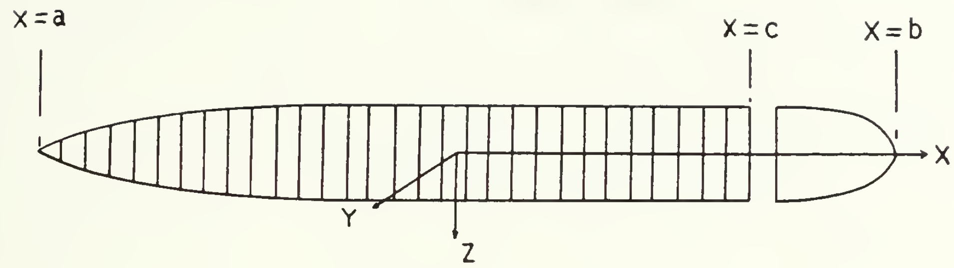

FIGURE D-1. Slender Axisymmetric Body Divided Into Two Sections: An Afterbody to be Analyzed Using Two-Dimensional Theory and a Hemi-Ellipsoidal Bow to be Analyzed Using Three-Dimensional Theory.

The force acting on a two-dimensional segment can be expressed as:

$$F_{lateral}(\xi) = (\rho A + A_{22}) \frac{D}{Dt}[v(\xi)] \tag{D.1}$$

where ξ is a dummy variable representing the axial location of the segment; ρ is the fluid density; A is the cross sectional area of the body; (ρ A is the local mass of fluid displaced per unit length); A_{22} is the local transverse added mass of a two-dimensional cylinder with cross sectional area A. $\frac{D}{Dt}[v(\xi)]$ is the substantial derivative of the local transverse fluid velocity, that is, an expression of the transverse fluid acceleration as viewed from a coordinate system moving with a fluid particle.

Physically, $\rho A \frac{D}{Dt}[v(\xi)]$ represents the transverse

force on a segment due to its presence in an acceleration field which causes a pressure gradient at the segment's location. This force is dependent on the volume of the segment and is generally referred to as the Froude-Krylov force. The $A_{22} \frac{D}{Dt}[v(\xi)]$ term represents the effect of fluid acceleration relative to the segment. This is the so-called added mass force which depends on the segment shape.

Since the added mass of a two-dimensional cylinder is equal to ρA and A is equal to $\pi r(\xi)^2$, where $r(\xi)$ is the local body radius, equation (D.1) can be rewritten as:

$$F_{lateral}(\xi) = 2\pi\rho r(\xi)^2 \frac{D}{Dt}[v(\xi)] \tag{D.2}$$

The total hydrodynamic force on the after segment can now be determined by integrating equation (D.2) along the segment's length:

$$F_{lateral} = 2\pi\rho \int_a^c r(\xi)^2 \frac{D}{Dt}[v(\xi)]\, d\xi \tag{D.3}$$

Similarly, the yaw moment on the after section can be found:

$$M_z = 2\pi\rho \int_a^c \xi r(\xi)^2 \frac{D}{Dt}[v(\xi)]\, d\xi \tag{D.4}$$

The force on the hemi-ellipsoid can be obtained by taking the product of the average local substantial acceleration and the sum of its three-dimensional added mass plus the displaced fluid mass. This force represents the sum of the Froude-Krylov and added mass forces as previously discussed with the exception that a three-dimensional analysis applies here. The added mass of the hemi-ellipsoid can be approximated by

dividing by two the value calculated to be the added mass of the equivalent ellipsoid of which the hemi-ellipsoid is half. Lamb[4], in article 15, presents the information necessary to determine the added mass of an ellipsoid.

The moment on the forebody will be the product of this force and its moment arm from the origin. The center of force of the hemi-ellipsoid is approximated to be at its center of volume.

For the analyses herein, the Froude-Krylov assumption shall be invoked, that is, it will be assumed that the body's presence does not affect the pressure or acceleration fields around it. The acceleration can therefore be determined from the local velocity potential generated by all singularities external to the body as well as any uniform flow in which the body is located.

The substantial acceleration can be expressed as:

$$\frac{D}{Dt}[v(\xi)] = \frac{\partial v}{\partial t} + \frac{\partial v}{\partial x}\frac{\partial x}{\partial t} + \frac{\partial v}{\partial y}\frac{\partial y}{\partial t} + \frac{\partial v}{\partial z}\frac{\partial z}{\partial t} \,. \qquad (D.5)$$

Because the problem analyzed is for steady flow, $\frac{\partial v}{\partial t} = 0$. Also, since the acceleration is to be calculated along the body axis, by symmetry of the flow induced by the other body, $\frac{\partial z}{\partial t} = w = 0$.

Therefore,

$$\frac{D}{Dt}[v(\xi)] = \frac{\partial v}{\partial x} u + \frac{\partial v}{\partial y} v \tag{D.6}$$

$$= \frac{\partial^2 \phi}{\partial x \partial y} \frac{\partial \phi}{\partial x} + \frac{\partial^2 \phi}{\partial y^2} \frac{\partial \phi}{\partial y} \tag{D.7}$$

Because $\frac{\partial \phi}{\partial x} \cong U$, and since $U >> \frac{\partial \phi}{\partial y}$ and $\frac{\partial^2 \phi}{\partial x \partial y}$ is of the same order as $\frac{\partial^2 \phi}{\partial y^2}$, the contribution of the y component of transverse acceleration is negligible compared with the longitudinal component. For completeness, however, all terms will be retained.

Appendix E

Sinusoidal Wall Geometry

Figure E.1 defines the sinusoidal wall geometry used in this thesis. The wall is modeled using a large axisymmetric body whose radius varies sinusoidally in the longitudinal direction about a mean radius r_0. Mathematically, the wall surface can be described as

$$\eta(x_w) = r_0 - A_{wall} \, SIN[K_{wall}(x_w - d_L)]$$

where A_{wall} is the sinusoidal amplitude; K_{wall} is the wave number of the wall, that is $K_{wall} = 2\pi/\lambda_{wall}$ where λ_{wall} is the wall wavelength. d_L is the longitudinal distance from the origin of the body centered orthogonal axes (x=0) to the origin of the wall sinusoid (x_w=0) and expresses the phase of the sinusoid at a point on the wall located transversely across from the body origin.

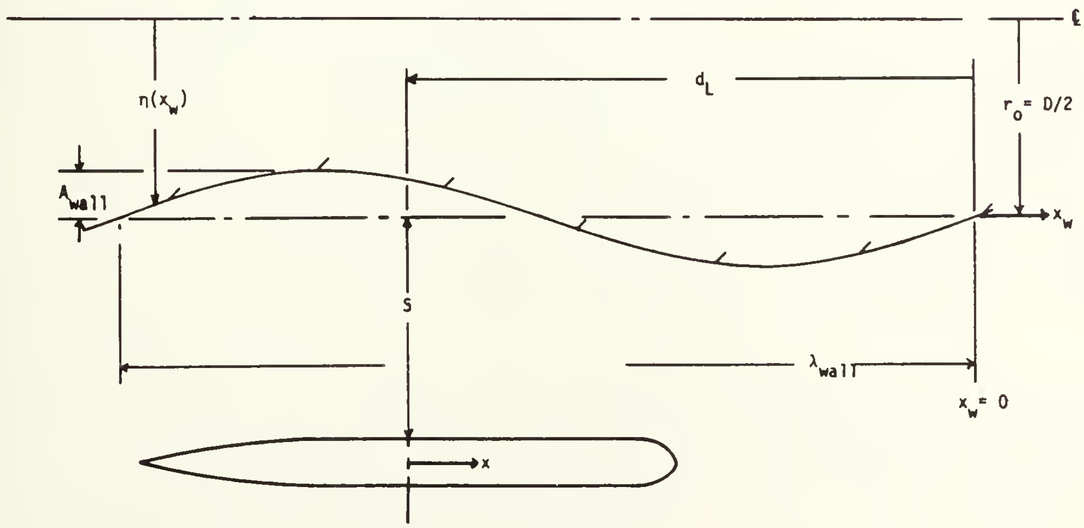

FIGURE E.1. Sinusoidal Wall Geometry

Appendix F

Description and Listing of Computer Programs Used in this Thesis

All computer programs listed in this appendix predict the force and moment on an unappended modern submarine hull form moving parallel to a wall in an ideal and otherwise infinite fluid. Axisymmetric bodies are modeled using continuous line distributions of sources and doublets; the dipole distribution is used to account for velocities induced on a body.

A brief description of each program follows:

1. "Flatwall.Bas" uses the method of images to account for a flat wall. The forces and moment are determined using Lagally's theorem.
2. "Flatwal2.Bas" also uses the method of images, however, the force and moment are determined using segmented theory.
3. "Slender.Bas" predicts the force and moment using Newman's slender body theory (Reference 2).
4. "Sinu1.Bas" models a sinusoidal wall as a "large" axisymmetric body with longitudinally varying sinusoidal radius in the proximity of a "small" modern submarine hull form. The force and moment are determined using Lagally's theorem.
5. "Sinu2.Bas" also models the sinusoidal wall using a "large" axisymmetric body, however, the force and moment are calculated using segmented theory.

Listing of Significant Variables Used in The Computer Programs

ADMASSFACT - Ratio of the added mass to the displaced mass of the ellipsoidal bow; this factor can be determined using Article 115 of Lamb[4].

AMP - Amplitude of the sinusoidal wall.

AVGACC - Average fluid acceleration acting on the ellipsoidal bow.

BB - Ratio of large sinusoidal body diameter to the diameter of the submarine hull form in proximity.

CENTVOL - Longitudinal center of volume of the ellipsoidal bow (from the forward perpendicular).

DIA - Maximum diameter of the submarine hull form.

DIPOLE - Local dipole strength along the body axis.

DIPOLEWAL - Local dipole strength of the large body used to approximate a wall.

FVEL - Forward velocity of the body in ft/sec.

FXTOTAL - Total force acting on the body in the X direction.

FYTOTAL - Total attraction force on the body.

KWALL - Wave number of the sinusoidal wall; KWALL $= \frac{2\pi}{\lambda_{wall}}$

LAB - After body length of the modern submarine hull form.

LENGTH - Length (overall) of the body.

LFB - Forebody length of the modern submarine hull form.

M,MM,MW - Simpson's multipliers.

MASSFOR - Fluid mass displaced by the ellipsoidal bow.

MZTOTAL - Total yaw moment acting on the body.

NUMPOINTS - Number of stations along the sinusoidal wall.

NUMSTA - Length of the ellipsoidal bow (in number of stations from the forward perpendicular).

PHIXY - ϕ_{xy}

PHIYY - ϕ_{yy}

R - Distance between a singularity point and a field point.

RAD - Local radius of the body.

RADP - Local slope of the body.

RO - Fluid density.

S - Station spacing of the body.

SZ - Station spacing of the ellipsoidal bow.

SOURCE - Local source strength along the body axis.

SOURCEWAL - Local source strength of the "large" body used to approximate a sinusoidal wall.

SW - Station spacing of the sinusoidal wall.

THETA - Phase of the sinusoidal wall as seen from the midships position of the body in proximity.

U - Induced longitudinal flow.

V - Induced transverse flow.

VIRTMASSFOR - Sum of the displaced mass and added mass, that is, the virtual mass of the ellipsoidal bow.

VOLFOR - Displaced volume of the ellipsoidal bow.

WALRAD - Local radius of the large body used to approximate the sinusoidal wall.

WALRADP - Local slope of the large body used to approximate the sinusoidal wall.

Y - Distance between the centerlines of two bodies in proximity.

Y1 - Separation distance between the outermost body surface and the wall.

Program Listings

```
10 '==========================================================
20 '                       FLATWAL1.BAS
30 '==========================================================
40 'NOTA BENE:FORCE IS IN LBS.;MOMENT IS IN FT.-LBS. ABOUT MIDSHIPS
50 PI=3.14159
60 DEFDBL A-Z
70 RO=2
80 CLS
90 PRINT
100 PRINT"THIS PROGRAM ANALYZES THE NEAR WALL ATTRACTION FORCE FOR A PARTICULAR"
110 PRINT"BODY OF REVOLUTION RUNNING PARALLEL TO A FLAT, INFINITE WALL"
120 PRINT"(HIT RETURN TO CONTINUE.)"
130 A$=INKEY$:IF A$="" GOTO 130
140 LPRINT"DIST TO WALL         FXTOTAL         FYTOTAL         MZTOTAL"
150 DIM PHIXY(41),PHIYY(41),PHIXY1(41),PHIYY1(41),SOURCE(41),DIPOLE(41),U(41)
160 DIM V(41),M(41),XI(41),XJ(41),RAD(41),RADP(41),FX(41),FY(41),MZ(41)
170 '==================================
180 'INPUT HULL GEOMETRY DESCRIPTION
190 INPUT"INPUT LOA,DIA OF SUBMARINE (ft.)";LENGTH,DIA
200 INPUT"INPUT FOREBODY LENGTH, FORWARD FULLNESS FACTOR";LFB,NF
210 INPUT"INPUT AFTERBODY LENGTH, AFTER FULLNESS FACTOR";LAB,NA
220 '==================================
230 'GENERATE HULL OFFSETS AND SLOPES
240 S=LENGTH/40
250 FOR J=0 TO 40
260 DIST=S*J
270 'FOREBODY
280 IF DIST>LFB GOTO 340
290 IF DIST=0 THEN DIST=.001
300 X=LFB-DIST
310 RAD(J)=(DIA/2)*(1-(X/LFB)^NF)^(1/NF)
320 RADP(J)=-(DIA/2)*(1/LFB)^NF*(X)^(NF-1)*(1-(X/LFB)^NF)^((1/NF)-1)
330 GOTO 430
340 'PARALLEL MIDBODY
350 IF DIST>(LENGTH-LAB) GOTO 390
360 RAD(J)=DIA/2
370 RADP(J)=0!
380 GOTO 430
390 'AFTERBODY
400 X=DIST-(LENGTH-LAB)
410 RAD(J)=(DIA/2)*(1-(X/LAB)^NA)
420 RADP(J)=NA*DIA/2/(LAB)^NA*X^(NA-1)
430 NEXT J
440 '==================================
450 'ESTABLISH SIMPSON MULTIPLIERS
460 FOR J=0 TO 40
470 IF INT(J/2)=J/2 THEN M(J)=2!
480 IF INT(J/2)<>J/2 THEN M(J)=4!
```

```
490 NEXT J
500 M(0)=1!:M(40)=1!
510 '================================
520 'INPUT DATA
530 CLS
540 PRINT"DO YOU WISH TO TERMINATE THIS PROGRAM? (Y/N)":A$=INKEY$
550 A$=INKEY$:IF A$="" GOTO 550
560 IF A$="Y" GOTO 1620
570 PRINT"INPUT FORWARD VELOCITY (KTS),SEPARATION DISTANCE (FT)":INPUT FVEL,Y1
580 'NOTE:SEPARATION DISTANCE BETWEEN OUTERMOST HULL SURFACE AND WALL.
590 Y=2*(DIA/2+Y1)
600 FVEL=1.689*FVEL
610 '===================================
620 'SEPARATE BODY INTO 41 STATIONS (FORWARD PERP=STATION 0,
630 'AFTER PERP=STATION 40) AND CALCULATE INITIAL SOURCE STRENGTH
640 'AT EACH STATION
650 FOR J=0 TO 40
660 SOURCE(J)=-FVEL*RAD(J)*RADP(J)/2
670 NEXT J
680 FOR L=0 TO 40
690 U(L)=0:V(L)=0
700 DIPOLE(L)=0
710 NEXT L
720 FOR P=1 TO 3
730 '===============================
740 'CALCULATE IMAGE DIPOLE STRENGTH
750 GOSUB 1300
760 FOR I=0 TO 40
770 DIPOLE(I)=V(I)*RAD(I)^2/2
780 'BODY DIPOLE STRENGTH WILL BE IN THE OPPOSITE DIRECTION OF THAT
790 'OF THE IMAGE (DIPOLE(I)).
800 NEXT I
810 '===============================
820 'CALCULATE SOURCE STRENGTH
830 GOSUB 1450
840 FOR I=0 TO 40
850 SOURCE(I)=-(FVEL-U(I))*RAD(I)*RADP(I)/2
860 NEXT I
870 NEXT P
880 GOSUB 1450
890 '================================
900 'CALCULATE POTENTIAL GRADIENTS INDUCED ON BODY AXIS BY IMAGE
910 'NOTE:ON BODY AXIS BECAUSE THAT IS WHERE THE SINGULARITY DISTRIBUTION IS.
920 FOR I=0 TO 40
930 XI(I)=LENGTH/2-I*S
940 PHIXY(I)=0:PHIYY(I)=0
950 PPHIXYA=0:PPHIYYA=0
960 FOR J=0 TO 40
```

```
970 XJ(J)=LENGTH/2-J*S
980 X=XI(I)-XJ(J)
990 R=(X^2+Y^2)^.5
1000 PPHIXY1=-3*X*(SOURCE(J)*Y-DIPOLE(J))/R^5
1010 PPHIXYA=(PPHIXY1-15*DIPOLE(J)*X*Y^2/R^7)*M(J)+PPHIXYA
1020 PPHIYY1=-3*Y*(SOURCE(J)*Y-3*DIPOLE(J))/R^5
1030 PPHIYYA=(PPHIYY1+SOURCE(J)/R^3-15*DIPOLE(J)*Y^3/R^7)*M(J)+PPHIYYA
1040 NEXT J
1050 PHIXY(I)=S/3*PPHIXYA
1060 PHIYY(I)=S/3*PPHIYYA
1070 NEXT I
1080 '==============================
1090 'CALCULATE FORCE AND MOMENT AT EACH STATION ON BODY
1100 FXTOTAL=0
1110 FYTOTAL=0
1120 MZTOTAL=0
1130 FOR I=0 TO 40
1140 XI(I)=LENGTH/2-I*S
1150 FX(I)=(-4*PI*RO*(SOURCE(I)*U(I)+(-DIPOLE(I))*PHIXY(I)))*M(I)
1160 FY(I)=(-4*PI*RO*(SOURCE(I)*V(I)+(-DIPOLE(I))*PHIYY(I)))*M(I)
1170 'MINUS SIGN BEFORE DIPOLE STRENGTH SINCE BODY DIPOLE IS IN OPPOSITE
1180 'DIRECTION OF IMAGE DIPOLE.
1190 MZ(I)=(XI(I)*FY(I))+(4*PI*RO*-DIPOLE(I)*U(I))*M(I)
1200 'MOMENT ABOUT MIDSHIPS
1210 FXTOTAL=FX(I)+FXTOTAL
1220 FYTOTAL=FY(I)+FYTOTAL
1230 MZTOTAL=MZ(I)+MZTOTAL
1240 NEXT I
1250 FXTOTAL=FXTOTAL*S/3
1260 FYTOTAL=FYTOTAL*S/3
1270 MZTOTAL=MZTOTAL*S/3
1280 LPRINT"    ";Y1;"              ";FXTOTAL;"        ";FYTOTAL;"      ";MZTOTAL
1290 GOTO 530
1300 '===============================
1310 'ROUTINE TO CALCULATE CROSSFLOW VELOCITY INDUCED (BY IMAGE) ON BODY SURFACE.
1320 'SURFACE.
1330 FOR I=0 TO 40
1340 XI(I)=LENGTH/2-I*S
1350 VV1=0
1360 FOR J=0 TO 40
1370 XJ(J)=LENGTH/2-J*S
1380 X=XI(I)-XJ(J)
1390 R=(X^2+(Y-RAD(I))^2)^.5
1400 VV1=((-DIPOLE(J)+SOURCE(J)*(Y-RAD(I)))/R^3+(3*DIPOLE(J)*(Y-RAD(I))^2)/R^5)*M(J)+VV1
1410 NEXT J
1420 V(I)=S*VV1/3
1430 NEXT I
1440 RETURN
```

```
1450 '==============================
1460 'ROUTINE TO CALCULATE VELOCITY INDUCED (BY IMAGE) ON BODY AXIS.
1470 FOR I=0 TO 40
1480 XI(I)=LENGTH/2-I*S
1490 UU1=0
1500 VV1=0
1510 FOR J=0 TO 40
1520 XJ(J)=LENGTH/2-J*S
1530 X=XI(I)-XJ(J)
1540 R=(X^2+Y^2)^.5
1550 UU1=(SOURCE(J)*X/R^3+(3*DIPOLE(J)*Y*X)/R^5)*M(J)+UU1
1560 VV1=((-DIPOLE(J)+SOURCE(J)*Y)/R^3+(3*DIPOLE(J)*Y^2)/R^5)*M(J)+VV1
1570 NEXT J
1580 U(I)=S*UU1/3
1590 V(I)=S*VV1/3
1600 NEXT I
1610 RETURN
1620 END
```

```
10 '=========================================================
20 '                       FLATWAL2.BAS
30 '=========================================================
40 'NOTA BENE:FORCE IS IN LBS.;MOMENT IS IN FT.-LBS. ABOUT MIDSHIPS
50 PI=3.14159
60 DEFDBL A-Z
70 RO=2
80 CLS
90 PRINT
100 PRINT"THIS PROGRAM ANALYZES THE NEAR WALL ATTRACTION FORCE FOR A PARTICULAR"
110 PRINT"BODY OF REVOLUTION RUNNING PARALLEL TO A FLAT, INFINITE WALL"
120 PRINT"(HIT RETURN TO CONTINUE.)"
130 A$=INKEY$:IF A$="" GOTO 130
140 DIM PHIXY(41),PHIYY(41),PHIYYY(41),PHIYY1(41),SOURCE(41),DIPOLE(41),U(41)
150 DIM V(41),M(41),MW(41),XI(41),XJ(41),RAD(41),RADP(41),FX(41),FY(41),MZ(41)
160 DIM XW(41),RAD11(10),FYU(40),MZU(40),PHIXYY(40),MM(40)
170 '=================================
180 'INPUT HULL GEOMETRY DESCRIPTION
190 INPUT"INPUT LOA,DIA OF SUBMARINE (ft.)";LENGTH,DIA
200 INPUT"INPUT FOREBODY LENGTH, FORWARD FULLNESS FACTOR";LFB,NF
210 INPUT"INPUT AFTERBODY LENGTH, AFTER FULLNESS FACTOR";LAB,NA
220 INPUT"INPUT NUMBER OF FORWARD STATIONS (MUST BE EVEN!)";NUMSTA
230 'NUMSTA IS THE NUMBER OF STATIONS FROM THE BOW (STATION 0) FOR WHICH
240 'STRIP THEORY WILL NOT BE USED.  THE ADDED MASS FOR THIS PORTION OF
250 'THE BODY WILL BE APPROXIMATED AS FOR A 3-DIMENSIONAL ELLIPSOID.
260 '=================================
270 'GENERATE HULL OFFSETS AND SLOPES
280 S=LENGTH/40
290 FOR J=0 TO 40
300 DIST=S*J
310 'FOREBODY
320 IF DIST>LFB GOTO 380
330 IF DIST=0 THEN DIST=.001
340 X=LFB-DIST
350 RAD(J)=(DIA/2)*(1-(X/LFB)^NF)^(1/NF)
360 RADP(J)=-(DIA/2)*(1/LFB)^NF*(X)^(NF-1)*(1-(X/LFB)^NF)^((1/NF)-1)
370 GOTO 470
380 'PARALLEL MIDBODY
390 IF DIST>(LENGTH-LAB) GOTO 430
400 RAD(J)=DIA/2
410 RADP(J)=0!
420 GOTO 470
430 'AFTERBODY
440 X=DIST-(LENGTH-LAB)
450 RAD(J)=(DIA/2)*(1-(X/LAB)^NA)
460 RADP(J)=NA*DIA/2/(LAB)^NA*X^(NA-1)
470 NEXT J
480 '=================================
```

```
490 'GENERATE OFFSETS FOR FOREBODY ELLIPSE (FOR ADDED MASS CALCULATIONS).
500 S2=NUMSTA*S/10
510 FOR J=0 TO 10
520 DIST=S2*J
530 IF DIST=0 THEN DIST=.0001
540 X=LFB-DIST
550 RAD11(J)=(DIA/2)*(1-(X/LFB)^NF)^(1/NF)
560 NEXT J
570 '=================================
580 'ESTABLISH SIMPSON MULTIPLIERS
590 FOR J=0 TO 40-NUMSTA
600 IF INT(J/2)=J/2 THEN M(J)=2!
610 IF INT(J/2)<>J/2 THEN M(J)=4!
620 MM(J)=M(J)
630 NEXT J
640 M(0)=1!:M(40-NUMSTA)=1!
650 MM(10)=1!:MM(0)=1!
660 FOR J=0 TO 40
670 IF INT(J/2)=J/2 THEN MW(J)=2!
680 IF INT(J/2)<>J/2 THEN MW(J)=4!
690 NEXT J
700 MW(0)=1!:MW(40)=1!
710 '=================================
720 'INPUT DATA
730 CLS
740 PRINT"DO YOU WISH TO TERMINATE THIS PROGRAM? (Y/N)":A$=INKEY$
750 A$=INKEY$:IF A$="" GOTO 750
760 IF A$="Y" GOTO 2170
770 PRINT"INPUT FORWARD VELOCITY (KTS),SEPARATION DISTANCE (FT)":INPUT FVEL,Y1
780 'NOTE: SEPARATION DISTANCE BETWEEN OUTERMOST HULL SURFACE AND WALL.
790 Y=2*(DIA/2+Y1)
800 FVEL=1.689*FVEL
810 '====================================
820 'SEPARATE BODY INTO 41 STATIONS (FORWARD PERP=STATION 0,
830 'AFTER PERP=STATION 40) AND CALCULATE INITIAL SOURCE STRENGTH
840 'AT EACH STATION
850 FOR J=0 TO 40
860 SOURCE(J)=-FVEL*RAD(J)*RADP(J)/2
870 NEXT J
880 FOR L=0 TO 40
890 U(L)=0:V(L)=0
900 DIPOLE(L)=0
910 NEXT L
920 FOR P=1 TO 3
930 '===============================
940 'CALCULATE IMAGE DIPOLE STRENGTH
950 GOSUB 1860
960 FOR I=0 TO 40
```

```
970 DIPOLE(I)=V(I)*RAD(I)^2/2
980 'BODY DIPOLE STRENGTH WILL BE IN THE OPPOSITE DIRECTION OF THAT
990 'OF THE IMAGE (DIPOLE(I)).
1000 NEXT I
1010 '===============================
1020 'CALCULATE SOURCE STRENGTH
1030 GOSUB 2000
1040 FOR I=0 TO 40
1050 SOURCE(I)=-(FVEL-U(I))*RAD(I)*RADP(I)/2
1060 NEXT I
1070 NEXT P
1080 '================================
1090 'CALCULATE POTENTIAL GRADIENTS INDUCED ON BODY AXIS BY THE WALL
1100 FOR I=0 TO 40-NUMSTA
1110 XI(I)=LENGTH/2-I*S-NUMSTA*S
1120 PHIYY(I)=0:PHIXY(I)=0
1130 PPHIYYA=0:PPHIXYA=0
1140 UU1=0!:VV1=0!
1150 FOR J=0 TO 40
1160 XW(J)=LENGTH/2-J*S
1170 X=XI(I)-XW(J)
1180 R=(X^2+Y^2)^.5
1190 PPHIYY1=-3*Y*(SOURCE(J)*Y-3*DIPOLE(J))/R^5
1200 PPHIYYA=(PPHIYY1+SOURCE(J)/R^3-15*DIPOLE(J)*Y^3/R^7)*MW(J)+PPHIYYA
1210 VV1=((-DIPOLE(J)+SOURCE(J)*(Y))/R^3+(3*DIPOLE(J)*(Y)^2)/R^5)*MW(J)+VV1
1220 PPHIXY1=-3*X*(SOURCE(J)*Y-DIPOLE(J))/R^5
1230 PPHIXYA=(PPHIXY1-15*DIPOLE(J)*X*Y^2/R^7)*MW(J)+PPHIXYA
1240 UU1=(SOURCE(J)*X/R^3+(3*DIPOLE(J)*Y*X)/R^5)*MW(J)+UU1
1250 NEXT J
1260 PHIYY(I)=S/3*PPHIYYA
1270 PHIXY(I)=S/3*PPHIXYA
1280 V(I)=S*VV1/3
1290 U(I)=S*UU1/3
1300 NEXT I
1310 '=================================
1320 'CALCULATE FORCE AND MOMENT AT EACH STATION ON BODY
1330 FYTOTAL=0
1340 MZTOTAL=0
1350 FOR I=0 TO 40-NUMSTA
1360 XI(I)=LENGTH/2-(I+NUMSTA)*S
1370 FY(I)=V(I)*PHIYY(I)*RO*PI*RAD(I+NUMSTA)^2*2*M(I)
1380 FYU(I)=(U(I)-FVEL)*PHIXY(I)*RO*PI*RAD(I+NUMSTA)^2*2*M(I)
1390 MZ(I)=FY(I)*XI(I)
1400 MZU(I)=FYU(I)*XI(I)
1410 FYTOTAL=FY(I)+FYU(I)+FYTOTAL
1420 MZTOTAL=MZ(I)+MZU(I)+MZTOTAL
1430 NEXT I
1440 FYTOTAL=FYTOTAL*S/3
```

```
1450 MZTOTAL=MZTOTAL*S/3
1460 SOUND 440,10
1470 PRINT"INPUT THE LATERAL ADDED MASS FACTOR FOR AN ELLIPSOID WITH L/D= ";NUMSTA*S/(RAD11(10))
1480 INPUT ADMASSFACT
1490 FOR I=0 TO 10
1500 XI(I)=LENGTH/2-I*S2
1510 PHIYYY(I)=0:PHIXYY(I)=0
1520 UU1=0:VV1=0
1530 PPHIYYA=0:PPHIXYA=0
1540 FOR J=0 TO 40
1550 XW(J)=LENGTH/2-J*S
1560 X=XI(I)-XW(J)
1570 R=(X^2+Y^2)^.5
1580 PPHIYY1=-3*Y*(SOURCE(J)*Y-3*DIPOLE(J))/R^5
1590 PPHIYYA=(PPHIYY1+SOURCE(J)/R^3-15*DIPOLE(J)*Y^3/R^7)*MW(J)+PPHIYYA
1600 VV1=((-DIPOLE(J)+SOURCE(J)*(Y))/R^3+(3*DIPOLE(J)*(Y)^2)/R^5)*MW(J)+VV1
1610 PPHIXY1=-3*X*(SOURCE(J)*Y-DIPOLE(J))/R^5
1620 PPHIXYA=(PPHIXY1-15*DIPOLE(J)*X*Y^2/R^7)*MW(J)+PPHIXYA
1630 UU1=(SOURCE(J)*X/R^3+(3*DIPOLE(J)*Y*X)/R^5)*MW(J)+UU1
1640 NEXT J
1650 PHIYYY(I)=S/3*PPHIYYA
1660 PHIXYY(I)=S/3*PPHIXYA
1670 V(I)=S*VV1/3
1680 U(I)=S*UU1/3
1690 PRINT PHIYYY(I)*V(I);"     ";PHIXYY(I)*(U(I)-FVEL)
1700 NEXT I
1710 SUM=0
1720 FOR J=0 TO 10:SUM=SUM+V(J)*PHIYYY(J)+(U(J)-FVEL)*PHIXYY(J):NEXT J
1730 AVGACC=SUM/11
1740 VOLFOR=0:CENTVOL=0
1750 FOR J=0 TO 10
1760 VOLFOR=VOLFOR+PI*RAD11(J)^2*MM(J)
1770 CENTVOL=CENTVOL+PI*RAD11(J)^2*MM(J)*J*S2
1780 NEXT J
1790 MASSFOR=RO*VOLFOR*S2/3
1800 CENTVOL=CENTVOL/VOLFOR
1810 VIRTMASSFOR=(1+ADMASSFACT)*MASSFOR
1820 FYTOTAL=FYTOTAL+AVGACC*VIRTMASSFOR
1830 MZTOTAL=MZTOTAL+AVGACC*VIRTMASSFOR*(LENGTH/2-CENTVOL)
1840 PRINT FYTOTAL,MZTOTAL
1850 GOTO 710
1860 '==============================
1870 'ROUTINE TO CALCULATE CROSSFLOW VELOCITY INDUCED (BY IMAGE) ON BODY SURFACE.
1880 FOR I=0 TO 40
1890 XI(I)=LENGTH/2-I*S
1900 VV1=0
1910 FOR J=0 TO 40
1920 XJ(J)=LENGTH/2-J*S
```

```
1930 X=XI(I)-XJ(J)
1940 R=(X^2+(Y-RAD(I))^2)^.5
1950 VV1=((-DIPOLE(J)+SOURCE(J)*(Y-RAD(I)))/R^3+(3*DIPOLE(J)*(Y-RAD(I))^2)/R^5)*MW(J)+VV1
1960 NEXT J
1970 V(I)=S*VV1/3
1980 NEXT I
1990 RETURN
2000 '===============================
2010 'ROUTINE TO CALCULATE VELOCITY INDUCED (BY IMAGE) ON BODY AXIS.
2020 FOR I=0 TO 40
2030 XI(I)=LENGTH/2-I*S
2040 UU1=0
2050 VV1=0
2060 FOR J=0 TO 40
2070 XJ(J)=LENGTH/2-J*S
2080 X=XI(I)-XJ(J)
2090 R=(X^2+Y^2)^.5
2100 UU1=(SOURCE(J)*X/R^3+(3*DIPOLE(J)*Y*X)/R^5)*MW(J)+UU1
2110 VV1=((-DIPOLE(J)+SOURCE(J)*Y)/R^3+(3*DIPOLE(J)*Y^2)/R^5)*MW(J)+VV1
2120 NEXT J
2130 U(I)=S*UU1/3
2140 V(I)=S*VV1/3
2150 NEXT I
2160 RETURN
2170 END
```

```
10 '===================================================================
20 '                              SLENDER.BAS
30 '===================================================================
40 '
50  CLS
60  DEFDBL A-H,K-Z
70  DIM RAD(41),RADP(41),M(41)
80 'PROGRAM TO CALCULATE SLENDER BODY THEORY ATTRACTION
90 'FORCE ON A BODY RUNNING PARALLEL TO A FLAT WALL.
100 'DENSITY=2.
110 '=================================
120 'INPUT HULL GEOMETRY DESCRIPTION
130  INPUT"INPUT LOA,DIA OF SUBMARINE (ft.)";LENGTH,DIA
140  INPUT"INPUT FOREBODY LENGTH, FORWARD FULLNESS FACTOR";LFB,NF
150  INPUT"INPUT AFTERBODY LENGTH, AFTER FULLNESS FACTOR";LAB,NA
160 '=================================
170 'GENERATE HULL OFFSETS AND SLOPES
180 S=LENGTH/40
190 FOR J=0 TO 40
200 DIST=S*J
210 'FOREBODY
220 IF DIST>LFB GOTO 280
230 IF DIST=0 THEN DIST=.001
240 X=LFB-DIST
250 RAD(J)=(DIA/2)*(1-(X/LFB)^NF)^(1/NF)
260 RADP(J)=-(DIA/2)*(1/LFB)^NF*(X)^(NF-1)*(1-(X/LFB)^NF)^((1/NF)-1)
270 GOTO 370
280 'PARALLEL MIDBODY
290 IF DIST>(LENGTH-LAB) GOTO 330
300 RAD(J)=DIA/2
310 RADP(J)=0!
320 GOTO 370
330 'AFTERBODY
340 X=DIST-(LENGTH-LAB)
350 RAD(J)=(DIA/2)*(1-(X/LAB)^NA)
360 RADP(J)=NA*DIA/2/(LAB)^NA*X^(NA-1)
370 NEXT J
380 '==============================
390 'ESTABLISH SIMPSON MULTIPLIERS
400 FOR I=1 TO 39
410 IF INT(I/2)=I/2 THEN M(I)=2
420 IF INT(I/2)<>I/2 THEN M(I)=4
430 NEXT I
440 M(0)=1:M(40)=1
450 FORCE=0:MOMTOT=0
460 '==============================
470 'INPUT DATA
480 PRINT"INPUT VALUE FOR VELOCITY (KTS), DISTANCE FROM WALL (FT)":INPUT V1,Y1
```

```
490 'NOTE:DISTANCE IS BETWEEN OUTERMOST HULL SURFACE AND WALL
500 Y=(Y1+DIA/2)
510 V=V1*1.688
520 A=V^2*6.28319:'PI*RO
530 FOR I=0 TO 40
540 T=(RAD(I)*RADP(I))^2
550 TT=(Y^2-RAD(I)^2)^-.5
560 TTT=M(I)*T*TT
570 FORCE=TTT+FORCE
580 X=LENGTH/2-I*S
590 MOM=TTT*X
600 MOMTOT=MOM+MOMTOT
610 NEXT I
620 FORCE=-FORCE*S*A/3
630 MOMTOT=MOMTOT*S*A/3
640 PRINT"VELOCITY(KTS)=";V1;" DIST(FT)=";Y1;" FORCE=";FORCE;" MOMENT=";MOMTOT
650 'NOTE:FORCE IS IN lbs;MOMENT IS IN FT-lbs ABOUT MIDSHIPS
660 GOTO 450
670 END
```

```
10 '====================================================
20 '                      SINU1.BAS
30 '====================================================
40 '
50 PI=3.14159
60 CLS
70 PRINT
80 PRINT"THIS PROGRAM ANALYZES THE NEAR WALL ATTRACTION FORCE FOR A PARTICULAR"
90 PRINT"BODY OF REVOLUTION RUNNING PARALLEL TO A SINUSOIDAL WALL"
100 PRINT"(HIT RETURN TO CONTINUE.)"
110 A$=INKEY$:IF A$="" GOTO 110
120 DIM PHIXY(41),PHIYY(41),PHIXY1(41),PHIYY1(41),SOURCE(41),DIPOLE(41),U(400)
130 DIM V(400),M(41),XI(100),XJ(100),RAD(41),RADP(41),FX(41),FY(41),MZ(41)
140 DIM XW(400),WALRAD(400),WALRADP(400),MW(400),SOURCEWAL(400),DIPOLEWAL(400)
150 '=================================
160 'INPUT HULL GEOMETRY DESCRIPTION
170 INPUT"INPUT LOA,DIA OF SUBMARINE (ft.)";LENGTH,DIA
180 INPUT"INPUT FOREBODY LENGTH, FORWARD FULLNESS FACTOR";LFB,NF
190 INPUT"INPUT AFTERBODY LENGTH, AFTER FULLNESS FACTOR";LAB,NA
200 '=================================
210 'GENERATE HULL OFFSETS AND SLOPES
220 S=LENGTH/40
230 FOR J=0 TO 40
240 DIST=S*J
250 'FOREBODY
260 IF DIST>LFB GOTO 320
270 IF DIST=0 THEN DIST=.001
280 X=LFB-DIST
290 RAD(J)=(DIA/2)*(1-(X/LFB)^NF)^(1/NF)
300 RADP(J)=-(DIA/2)*(1/LFB)^NF*(X)^(NF-1)*(1-(X/LFB)^NF)^((1/NF)-1)
310 GOTO 410
320 'PARALLEL MIDBODY
330 IF DIST>(LENGTH-LAB) GOTO 370
340 RAD(J)=DIA/2
350 RADP(J)=0!
360 GOTO 410
370 'AFTERBODY
380 X=DIST-(LENGTH-LAB)
390 RAD(J)=(DIA/2)*(1-(X/LAB)^NA)
400 RADP(J)=NA*DIA/2/(LAB)^NA*X^(NA-1)
410 NEXT J
420 '=================================
430 'ESTABLISH SIMPSON MULTIPLIERS
440 FOR J=0 TO 40
450 IF INT(J/2)=J/2 THEN M(J)=2!
460 IF INT(J/2)<>J/2 THEN M(J)=4!
470 NEXT J
480 M(0)=1!:M(40)=1!
```

```
490 '=================================
500 'INPUT DATA
510 CLS
520 PRINT"DO YOU WISH TO TERMINATE THIS PROGRAM? (Y/N)":A$=INKEY$
530 A$=INKEY$:IF A$="" GOTO 530
540 IF A$="Y" GOTO 1790
550 PRINT"INPUT FORWARD VELOCITY (KTS),SEPARATION DISTANCE (FT)":INPUT FVEL,Y1
560 'NOTE: SEPARATION DISTANCE BETWEEN OUTERMOST HULL SURFACE AND WALL.
570 PRINT"INPUT SIZE OF LARGE BODY IN NUMBER OF DIAMETERS OF SMALL BODY.":INPUT BB
580 Y=Y1+(BB/2+.5)*DIA
590 FVEL=1.689*FVEL
600 RO=2
610 '=================================
620 'INPUT INFORMATION CONCERNING WALL
630 '
640 PRINT"INPUT LENGTH OF WALL WAVE,AMPLITUDE":INPUT LW,AMP
650 KWALL=2*PI/LW
660 FOR THETA=0 TO LW STEP LW/10
670 IF LW<LENGTH GOTO 770
680 SW=4!*LENGTH/80
690 FOR J=0 TO 80
700 XW(J)=2!*LENGTH-J*SW
710 WALRAD(J)=(BB*DIA)/2-AMP*SIN(KWALL*(XW(J)-THETA))
720 WALRADP(J)=-AMP*KWALL*COS(KWALL*(XW(J)-THETA))
730 NEXT J
740 NUMPOINTS=81
750 GOTO 860
760 'FOR CORRECT OPERATION, LENGTH/LW=AN EVEN INTEGER
770 NUMPOINTS=17+16*INT((4!*LENGTH/LW)-1)
780 SW=4!*LENGTH/(NUMPOINTS-1)
790 FOR J=0 TO NUMPOINTS-1
800 XW(J)=2!*LENGTH-J*SW
810 WALRAD(J)=(BB*DIA)/2-AMP*SIN(KWALL*(XW(J)-THETA))
820 WALRADP(J)=-AMP*KWALL*COS(KWALL*(XW(J)-THETA))
830 NEXT J
840 '=================================
850 'ESTABLISH SIMPSON MULTIPLIERS FOR THE WALL
860 FOR I=1 TO NUMPOINTS-2
870 IF I/2=INT(I/2) THEN MW(I)=2
880 IF I/2<>INT(I/2) THEN MW(I)=4
890 DIPOLEWAL(I)=0
900 NEXT I
910 DIPOLEWAL(0)=0!:DIPOLEWAL(NUMPOINTS-1)=0!
920 MW(0)=1!:MW(NUMPOINTS-1)=1!
930 '====================================
940 'SEPARATE BODY INTO 41 STATIONS (FORWARD PERP=STATION 0,
950 'AFTER PERP=STATION 40) AND CALCULATE INITIAL SOURCE STRENGTH
960 'AT EACH STATION
```

```
970 FOR J=0 TO 40
980 SOURCE(J)=-FVEL*RAD(J)*RADP(J)/2
990 NEXT J
1000 FOR L=0 TO 40
1010 U(L)=0:V(L)=0
1020 DIPOLE(L)=0
1030 NEXT L
1040 '
1050 '=============================
1060 'CALCULATE WALL SOURCE STRENGTH
1070 '
1080 GOSUB 1960
1090 FOR I=0 TO NUMPOINTS-1
1100 SOURCEWAL(I)=-(FVEL-U(I))*WALRAD(I)*WALRADP(I)/2
1110 NEXT I
1120 FOR T=1 TO 3
1130 '==============================
1140 'RESIZE BODY
1150 '
1160 GOSUB 2120
1170 FOR I=0 TO 40
1180 DIPOLE(I)=V(I)*RAD(I)^2/2
1190 NEXT I
1200 GOSUB 2270
1210 FOR I=0 TO 40
1220 SOURCE(I)=-(FVEL-U(I))*RAD(I)*RADP(I)/2
1230 NEXT I
1240 '=============================
1250 'RESIZE WALL DIPOLE
1260 GOSUB 1800
1270 FOR I=0 TO NUMPOINTS-1
1280 DIPOLEWAL(I)=-V(I)*WALRAD(I)^2/2
1290 NEXT I
1300 GOSUB 1960
1310 'RESIZE WALL SOURCE
1320 FOR I=0 TO NUMPOINTS-1
1330 SOURCEWAL(I)=-(FVEL-U(I))*WALRAD(I)*WALRADP(I)/2
1340 NEXT I
1350 NEXT T
1360 GOSUB 2270
1370 '===============================
1380 'CALCULATE POTENTIAL GRADIENTS INDUCED ON BODY AXIS BY THE WALL
1390 FOR I=0 TO 40
1400 XI(I)=LENGTH/2-I*S
1410 PHIXY(I)=0:PHIYY(I)=0
1420 PPHIXYA=0:PPHIYYA=0
1430 FOR J=0 TO NUMPOINTS-1
1440 XW(J)=2!*LENGTH-J*SW
```

```
1450 X=XI(I)-XW(J)
1460 R=(X^2+Y^2)^.5
1470 PPHIXY1=-3*X*(SOURCEWAL(J)*Y-DIPOLEWAL(J))/R^5
1480 PPHIXYA=(PPHIXY1-15*DIPOLEWAL(J)*X*Y^2/R^7)*MW(J)+PPHIXYA
1490 PPHIYY1=-3*Y*(SOURCEWAL(J)*Y-3*DIPOLEWAL(J))/R^5
1500 PPHIYYA=(PPHIYY1+SOURCEWAL(J)/R^3-15*DIPOLEWAL(J)*Y^3/R^7)*MW(J)+PPHIYYA
1510 NEXT J
1520 PHIXY(I)=SW/3*PPHIXYA
1530 PHIYY(I)=SW/3*PPHIYYA
1540 NEXT I
1550 'CALCULATE FORCE AND MOMENT AT EACH STATION ON BODY
1560 FXTOTAL=0
1570 FYTOTAL=0
1580 MZTOTAL=0
1590 FOR I=0 TO 40
1600 XI(I)=LENGTH/2-I*S
1610 FX(I)=(-4*PI*RO*(SOURCE(I)*U(I)+(-DIPOLE(I))*PHIXY(I)))*M(I)
1620 FY(I)=(-4*PI*RO*(SOURCE(I)*V(I)+(-DIPOLE(I))*PHIYY(I)))*M(I)
1630 'MINUS SIGN BEFORE DIPOLE STRENGTH SINCE BODY DIPOLE IS IN OPPOSITE
1640 'DIRECTION OF FLOW INDUCED BY THE "WALL"
1650 MZ(I)=(XI(I)*FY(I))+(4*PI*RO*-DIPOLE(I)*U(I))*M(I)
1660 'MOMENT ABOUT MIDSHIPS
1670 FXTOTAL=FX(I)+FXTOTAL
1680 FYTOTAL=FY(I)+FYTOTAL
1690 MZTOTAL=MZ(I)+MZTOTAL
1700 NEXT I
1710 FXTOTAL=FXTOTAL*S/3
1720 FYTOTAL=FYTOTAL*S/3
1730 MZTOTAL=MZTOTAL*S/3
1740 LPRINT"BB= ";BB;"  T=";T
1750 LPRINT"   ";Y1;"              ";FXTOTAL;"       ";FYTOTAL;"      ";MZTOTAL;"      ";THETA
1760 LPRINT
1770 NEXT THETA
1780 GOTO 510
1790 END
1800 '=============================
1810 'CALCULATE VELOCITY ALONG SINUSOIDAL WALL
1820 '
1830 'ROUTINE TO CALCULATE TRANSVERSE VELOCITY INDUCED (BY BODY) ON WALL.
1840 FOR I=0 TO NUMPOINTS-1
1850 XW(I)=2!*LENGTH-I*SW
1860 VV1=0
1870 FOR J=0 TO 40
1880 XJ(J)=LENGTH/2-J*S
1890 X=XW(I)-XJ(J)
1900 R=(X^2+(Y-WALRAD(I))^2)^.5
1910 VV1=((DIPOLE(J)+SOURCE(J)*(-Y+WALRAD(I)))/R^3+(-3*DIPOLE(J)*(-Y+WALRAD(I))^2)/R^5)*M(J)+VV1
1920 NEXT J
```

```
1930 V(I)=S*VV1/3
1940 NEXT I
1950 RETURN
1960 '==============================
1970 'CALCULATE VELOCITY ALONG SINUSOIDAL WALL AXIS
1980 '
1990 'ROUTINE TO CALCULATE LONGITUDINAL VELOCITY INDUCED (BY BODY) ON WALL.
2000 FOR I=0 TO NUMPOINTS-1
2010 XW(I)=2!*LENGTH-I*SW
2020 UU1=0
2030 FOR J=0 TO 40
2040 XJ(J)=LENGTH/2-J*S
2050 X=XW(I)-XJ(J)
2060 R=(X^2+(Y)^2)^.5
2070 UU1=(SOURCE(J)*X/R^3+(-3*DIPOLE(J)*(-Y)*X)/R^5)*M(J)+UU1
2080 NEXT J
2090 U(I)=S*UU1/3
2100 NEXT I
2110 RETURN
2120 '==============================
2130 'CALCULATE CROSSFLOW AT BODY SIDE DUE TO WALL
2140 '
2150 FOR I=0 TO 40
2160 XI(I)=LENGTH/2-I*S
2170 VV1=0!
2180 FOR J=0 TO NUMPOINTS-1
2190 XW(J)=2!*LENGTH-J*SW
2200 X=XI(I)-XW(J)
2210 R=(X^2+(Y-RAD(I))^2)^.5
2220 VV1=((-DIPOLEWAL(J)+SOURCEWAL(J)*(Y-RAD(I)))/R^3+(3*DIPOLEWAL(J)*(Y-RAD(I))^2)/R^5)*MW(J)+VV1
2230 NEXT J
2240 V(I)=SW*VV1/3
2250 NEXT I
2260 RETURN
2270 '==============================
2280 'CALCULATE LONGITUDINAL VELOCITY AT BODY AXIS DUE TO WALL
2290 '
2300 FOR I=0 TO 40
2310 UU1=0
2320 VV1=0
2330 XI(I)=LENGTH/2-I*S
2340 FOR J=0 TO NUMPOINTS-1
2350 XW(J)=2!*LENGTH-J*SW
2360 X=XI(I)-XW(J)
2370 R=(X^2+Y^2)^.5
2380 UU1=(SOURCEWAL(J)*X/R^3+(3*DIPOLEWAL(J)*Y*X)/R^5)*MW(J)+UU1
2390 VV1=((-DIPOLEWAL(J)+SOURCEWAL(J)*(Y))/R^3+(3*DIPOLEWAL(J)*(Y)^2)/R^5)*MW(J)+VV1
2400 NEXT J
```

```
2410 U(I)=SW*UU1/3
2420 V(I)=SW*VV1/3
2430 NEXT I
2440 RETURN
```

```
10 KEY OFF
20 '==========================================================
30 '                       SINU2.BAS
40 '==========================================================
50 '
60 DEFDBL A-H,M-S,U-Z
70 PI=3.14159
80 CLS
90 PRINT
100 PRINT"THIS PROGRAM ANALYZES THE NEAR WALL ATTRACTION FORCE FOR A "
110 PRINT"BODY OF REVOLUTION RUNNING PARALLEL TO A SINUSOIDAL WALL"
120 PRINT"(HIT RETURN TO CONTINUE.)"
130 A$=INKEY$:IF A$="" GOTO 130
140 DIM PHIXY(41),PHIYY(41),PHIYYY(41),PHIYY1(41),SOURCE(41),DIPOLE(41),U(400)
150 DIM V(400),M(41),XI(100),XJ(100),RAD(41),RADP(41),FX(41),FY(41),MZ(41)
160 DIM XW(400),WALRAD(400),WALRADP(400),MW(400),SOURCEWAL(400),DIPOLEWAL(400)
170 DIM MM(41),RAD11(10)
180 DIM FYU(40),MZU(40),PHIXYY(40)
190 '==================================
200 'INPUT HULL GEOMETRY DESCRIPTION
210 INPUT"INPUT LOA,DIA OF SUBMARINE (ft.)";LENGTH,DIA
220 INPUT"INPUT FOREBODY LENGTH, FORWARD FULLNESS FACTOR";LFB,NF
230 INPUT"INPUT AFTERBODY LENGTH, AFTER FULLNESS FACTOR";LAB,NA
240 INPUT"INPUT NUMBER OF FORWARD STATIONS (MUST BE EVEN!)";NUMSTA
250 'NOTE: NUMSTA IS THE NUMBER OF STATIONS FROM THE BOW (STATION 0) FOR WHICH
260 'STRIP THEORY WILL NOT BE USED.  THE ADDED MASS FOR THIS PORTION OF
270 'THE BODY WILL BE APPROXIMATED AS FOR A 3-DIMENSIONAL ELLIPSOID.
280 '==================================
290 'GENERATE HULL OFFSETS AND SLOPES
300 S=LENGTH/40
310 FOR J=0 TO 40
320 DIST=S*J
330 'FOREBODY
340 IF DIST>LFB GOTO 400
350 IF DIST=0 THEN DIST=.001
360 X=LFB-DIST
370 RAD(J)=(DIA/2)*(1-(X/LFB)^NF)^(1/NF)
380 RADP(J)=-(DIA/2)*(1/LFB)^NF*(X)^(NF-1)*(1-(X/LFB)^NF)^((1/NF)-1)
390 GOTO 490
400 'PARALLEL MIDBODY
410 IF DIST>(LENGTH-LAB) GOTO 450
420 RAD(J)=DIA/2
430 RADP(J)=0!
440 GOTO 490
450 'AFTERBODY
460 X=DIST-(LENGTH-LAB)
470 RAD(J)=(DIA/2)*(1-(X/LAB)^NA)
480 RADP(J)=NA*DIA/2/(LAB)^NA*X^(NA-1)
```

```
490 NEXT J
500 '=================================
510 'GENERATE OFFSETS FOR FOREBODY ELLIPSE (FOR ADDED MASS CALCULATIONS).
520  S2=NUMSTA*S/10
530  FOR J=0 TO 10
540  DIST=S2*J
550  IF DIST=0 THEN DIST=.0001
560  X=LFB-DIST
570  RAD11(J)=(DIA/2)*(1-(X/LFB)^NF)^(1/NF)
580  NEXT J
590 '=================================
600 'ESTABLISH SIMPSON MULTIPLIERS
610 FOR J=0 TO 40-NUMSTA
620 IF INT(J/2)=J/2 THEN M(J)=2!
630 IF INT(J/2)<>J/2 THEN M(J)=4!
640 MM(J)=M(J)
650 NEXT J
660 M(0)=1!:M(40-NUMSTA)=1!
670 MM(10)=1!:MM(0)=1!
680 '=================================
690 'INPUT DATA
700 CLS
710 PRINT"DO YOU WISH TO TERMINATE THIS PROGRAM? (Y/N)":A$=INKEY$
720 A$=INKEY$:IF A$="" GOTO 720
730 IF A$="Y" GOTO 2480
740 PRINT"INPUT FORWARD VELOCITY (KTS),SEPARATION DISTANCE (FT)":INPUT FVEL,Y1
750 'NOTE: SEPARATION DISTANCE BETWEEN OUTERMOST HULL SURFACE AND WALL.
760 PRINT"INPUT SIZE OF LARGE BODY IN NUMBER OF DIAMETERS OF SMALL BODY":INPUT BB
770 Y=Y1+(BB/2+.5)*DIA
780 FVEL=1.689*FVEL
790 RO=2
800 '=================================
810 'INPUT INFORMATION CONCERNING WALL
820 '
830 PRINT"INPUT LENGTH OF WALL WAVE,AMPLITUDE":INPUT LW,AMP
840 KWALL=2*PI/LW
850 FOR THETA=0 TO LW STEP LW/10
860 IF LW<LENGTH GOTO 960
870 SW=4!*LENGTH/80
880 FOR J=0 TO 80
890 XW(J)=2!*LENGTH-J*SW
900 WALRAD(J)=(BB*DIA)/2-AMP*SIN(KWALL*(XW(J)-THETA))
910 WALRADP(J)=-AMP*KWALL*COS(KWALL*(XW(J)-THETA))
920 NEXT J
930 NUMPOINTS=81
940 GOTO 1030
950 'FOR CORRECT OPERATION, LENGTH/LW=AN EVEN INTEGER
960 NUMPOINTS=17+16*INT((4!*LENGTH/LW)-1)
```

```
970 SW=4!*LENGTH/(NUMPOINTS-1)
980 FOR J=0 TO NUMPOINTS-1
990 XW(J)=2!*LENGTH-J*SW
1000 WALRAD(J)=(BB*DIA)/2-AMP*SIN(KWALL*(XW(J)-THETA))
1010 WALRADP(J)=-AMP*KWALL*COS(KWALL*(XW(J)-THETA))
1020 NEXT J
1030 FOR I=1 TO NUMPOINTS-2
1040 IF I/2=INT(I/2) THEN MW(I)=2
1050 IF I/2<>INT(I/2) THEN MW(I)=4
1060 DIPOLEWAL(I)=0
1070 NEXT I
1080 DIPOLEWAL(0)=0!:DIPOLEWAL(NUMPOINTS-1)=0!
1090 MW(0)=1!:MW(NUMPOINTS-1)=1!
1100 '==================================
1110 'SEPARATE BODY INTO 41 STATIONS (FORWARD PERP=STATION 0,
1120 'AFTER PERP=STATION 40) AND CALCULATE INITIAL SOURCE STRENGTH
1130 'AT EACH STATION
1140 FOR J=0 TO 40
1150 SOURCE(J)=-FVEL*RAO(J)*RADP(J)/2
1160 NEXT J
1170 FOR L=0 TO 40
1180 U(L)=0:V(L)=0
1190 DIPOLE(L)=0
1200 NEXT L
1210 '
1220 '============================
1230 'CALCULATE WALL SOURCE STRENGTH
1240 '
1250 GOSUB 2320
1260 FOR I=0 TO NUMPOINTS-1
1270 SOURCEWAL(I)=-(FVEL-U(I))*WALRAD(I)*WALRADP(I)/2
1280 NEXT I
1290 '=============================
1300 'SIZE WALL DIPOLE
1310 GOSUB 2150
1320 FOR I=0 TO NUMPOINTS-1
1330 DIPOLEWAL(I)=-V(I)*WALRAD(I)^2*.5
1340 NEXT I
1350 '==============================
1360 'CALCULATE POTENTIAL GRADIENTS INDUCED ON BODY AXIS BY THE WALL
1370 FOR I=0 TO 40-NUMSTA
1380 XI(I)=LENGTH/2-(I+NUMSTA)*S
1390 PHIYY(I)=0:PHIXY(I)=0
1400 PPHIYYA=0:PPHIXYA=0
1410 UU1=0!:VV1=0!
1420 FOR J=0 TO NUMPOINTS-1
1430 XW(J)=2!*LENGTH-J*SW
1440 X=XI(I)-XW(J)
```

```
1450 R=(X^2+Y^2)^.5
1460 PPHIYY1=-3*Y*(SOURCEWAL(J)*Y-3*DIPOLEWAL(J))/R^5
1470 PPHIYYA=(PPHIYY1+SOURCEWAL(J)/R^3-15*DIPOLEWAL(J)*Y^3/R^7)*MW(J)+PPHIYYA
1480 VV1=((-DIPOLEWAL(J)+SOURCEWAL(J)*(Y))/R^3+(3*DIPOLEWAL(J)*(Y)^2)/R^5)*MW(J)+VV1
1490 PPHIXY1=-3*X*(SOURCEWAL(J)*Y-DIPOLEWAL(J))/R^5
1500 PPHIXYA=(PPHIXY1-15*DIPOLEWAL(J)*X*Y^2/R^7)*MW(J)+PPHIXYA
1510 UU1=(SOURCEWAL(J)*X/R^3+(3*DIPOLEWAL(J)*Y*X)/R^5)*MW(J)+UU1
1520 NEXT J
1530 PHIYY(I)=SW/3*PPHIYYA
1540 PHIXY(I)=SW/3*PPHIXYA
1550 V(I)=SW*VV1/3
1560 U(I)=SW*UU1/3
1570 NEXT I
1580 'CALCULATE FORCE AND MOMENT AT EACH STATION ON BODY
1590 FYTOTAL=0
1600 MZTOTAL=0
1610 FOR I=0 TO 40-NUMSTA
1620 XI(I)=LENGTH/2-(I+NUMSTA)*S
1630 FY(I)=V(I)*PHIYY(I)*RO*PI*RAD(I+NUMSTA)^2*2*M(I)
1640 FYU(I)=(U(I)-FVEL)*PHIXY(I)*RO*PI*RAD(I+NUMSTA)^2*2*M(I)
1650 MZ(I)=FY(I)*XI(I)
1660 MZU(I)=FYU(I)*XI(I)
1670 FYTOTAL=FY(I)+FYU(I)+FYTOTAL
1680 MZTOTAL=MZ(I)+MZU(I)+MZTOTAL
1690 NEXT I
1700 FYTOTAL=FYTOTAL*S/3
1710 MZTOTAL=MZTOTAL*S/3
1720 SOUND 440,10
1730 IF ADMASSFACT<>0 GOTO 1760
1740 PRINT"INPUT THE LATERAL ADDED MASS FACTOR FOR AN ELLIPSOID WITH L/D= ";NUMSTA*S/(RAD11(10))
1750 INPUT ADMASSFACT
1760 FOR I=0 TO 10
1770 XI(I)=LENGTH/2-I*S2
1780 PHIYYY(I)=0:PHIXYY(I)=0
1790 UU1=0:VV1=0
1800 PPHIYYA=0:PPHIXYA=0
1810 FOR J=0 TO NUMPOINTS-1
1820 XW(J)=2!*LENGTH-J*SW
1830 X=XI(I)-XW(J)
1840 R=(X^2+Y^2)^.5
1850 PPHIYY1=-3*Y*(SOURCEWAL(J)*Y-3*DIPOLEWAL(J))/R^5
1860 PPHIYYA=(PPHIYY1+SOURCEWAL(J)/R^3-15*DIPOLEWAL(J)*Y^3/R^7)*MW(J)+PPHIYYA
1870 VV1=((-DIPOLEWAL(J)+SOURCEWAL(J)*(Y))/R^3+(3*DIPOLEWAL(J)*(Y)^2)/R^5)*MW(J)+VV1
1880 PPHIXY1=-3*X*(SOURCEWAL(J)*Y-DIPOLEWAL(J))/R^5
1890 PPHIXYA=(PPHIXY1-15*DIPOLEWAL(J)*X*Y^2/R^7)*MW(J)+PPHIXYA
1900 UU1=(SOURCEWAL(J)*X/R^3+(3*DIPOLEWAL(J)*Y*X)/R^5)*MW(J)+UU1
1910 NEXT J
1920 PHIYYY(I)=SW/3*PPHIYYA
```

```
1930 PHIXYY(I)=SW/3*PPHIXYA
1940 V(I)=SW*VV1/3
1950 U(I)=SW*UU1/3
1960 NEXT I
1970 SUM=0
1980 FOR J=0 TO 10:SUM=SUM+V(J)*PHIYYY(J)+(U(J)-FVEL)*PHIXYY(J):NEXT J
1990 AVGACC=SUM/11
2000 VOLFOR=0:CENTVOL=0
2010 FOR J=0 TO 10
2020 VOLFOR=VOLFOR+PI*RAD11(J)^2*MM(J)
2030 CENTVOL=CENTVOL+PI*RAD11(J)^2*MM(J)*J*S2
2040 NEXT J
2050 MASSFOR=RO*VOLFOR*S2/3
2060 CENTVOL=CENTVOL/VOLFOR
2070 VIRTMASSFOR=(1+ADMASSFACT)*MASSFOR
2080 FYTOTAL=FYTOTAL+AVGACC*VIRTMASSFOR
2090 MZTOTAL=MZTOTAL+AVGACC*VIRTMASSFOR*(LENGTH/2-CENTVOL)
2100 LPRINT Y1,BB,AMP
2110 LPRINT FYTOTAL,MZTOTAL
2120 LPRINT
2130 NEXT THETA
2140 GOTO 690
2150 '=============================
2160 'CALCULATE VELOCITY ALONG SINUSOIDAL WALL
2170 '
2180 'ROUTINE TO CALCULATE TRANSVERSE VELOCITY INDUCED (BY BODY) ON WALL.
2190 DD=0
2200 FOR I=0 TO NUMPOINTS-1
2210 XW(I)=2!*LENGTH-I*SW
2220 VV1=0
2230 FOR J=0 TO 40
2240 XJ(J)=LENGTH/2-J*S
2250 X=XW(I)-XJ(J)
2260 R=(X^2+(Y-WALRAD(I))^2)^.5
2270 VV1=((SOURCE(J)*(-Y+WALRAD(I)))/R^3)*M(J)+VV1
2280 NEXT J
2290 V(I)=S*VV1/3
2300 NEXT I
2310 RETURN
2320 '=============================
2330 'CALCULATE VELOCITY ALONG SINUSOIDAL WALL AXIS
2340 '
2350 'ROUTINE TO CALCULATE LONGITUDINAL VELOCITY INDUCED (BY BODY) ON WALL.
2360 FOR I=0 TO NUMPOINTS-1
2370 XW(I)=2!*LENGTH-I*SW
2380 UU1=0
2390 FOR J=0 TO 40
2400 XJ(J)=LENGTH/2-J*S
```

```
2410 X=XW(I)-XJ(J)
2420 R=(X^2+(Y)^2)^.5
2430 UU1=(SOURCE(J)*X/R^3)*M(J)+UU1
2440 NEXT J
2450 U(I)=S*UU1/3
2460 NEXT I
2470 RETURN
2480 END
```

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c. 1 The force and moment on a submerged axisymmetric body moving near a sinusoidal wall.

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